

Rockets and Space Travel

THE FUTURE OF FLIGHT BEYOND
THE STRATOSPHERE

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Rockets AND SPACE TRAVEL

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WILLY LEY

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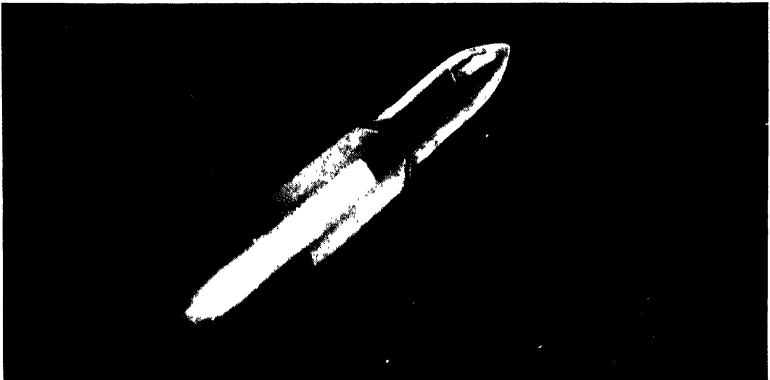
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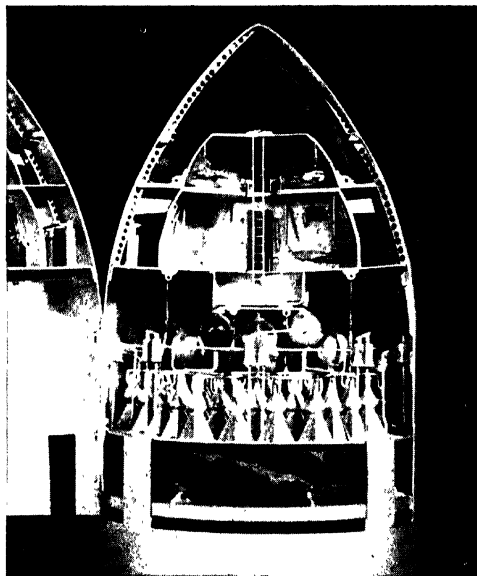
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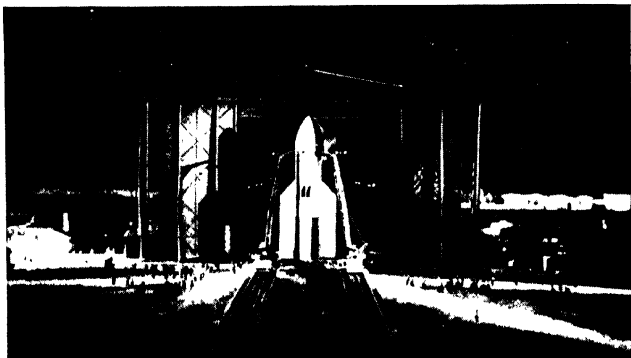
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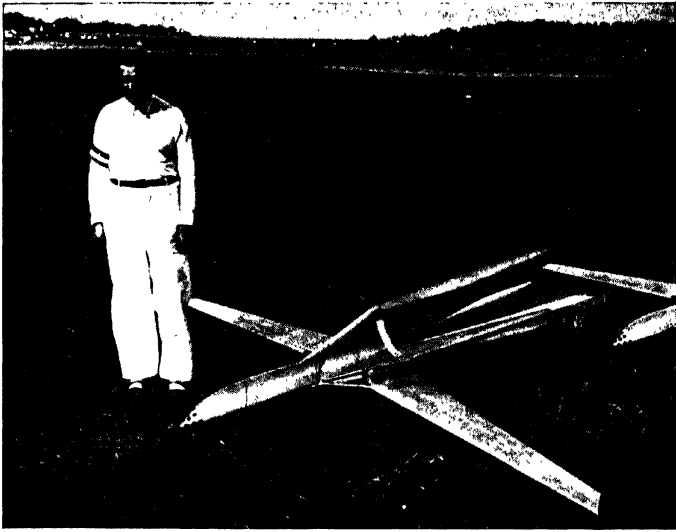
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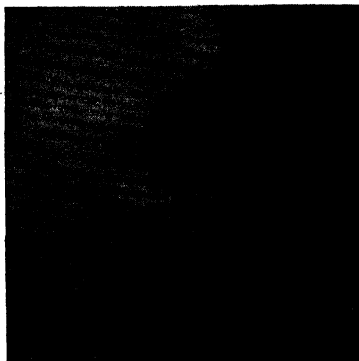
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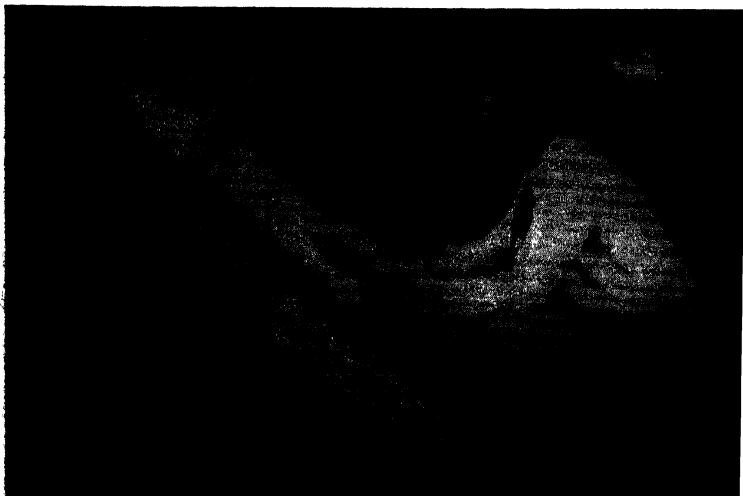
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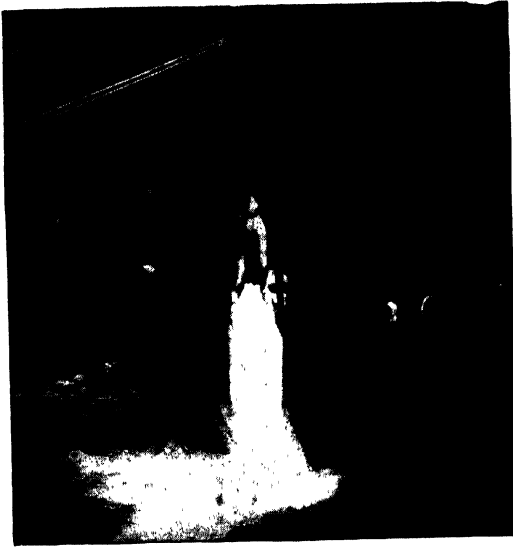


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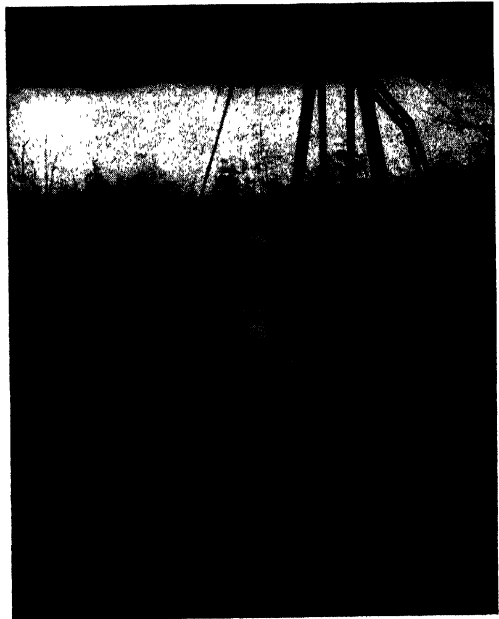


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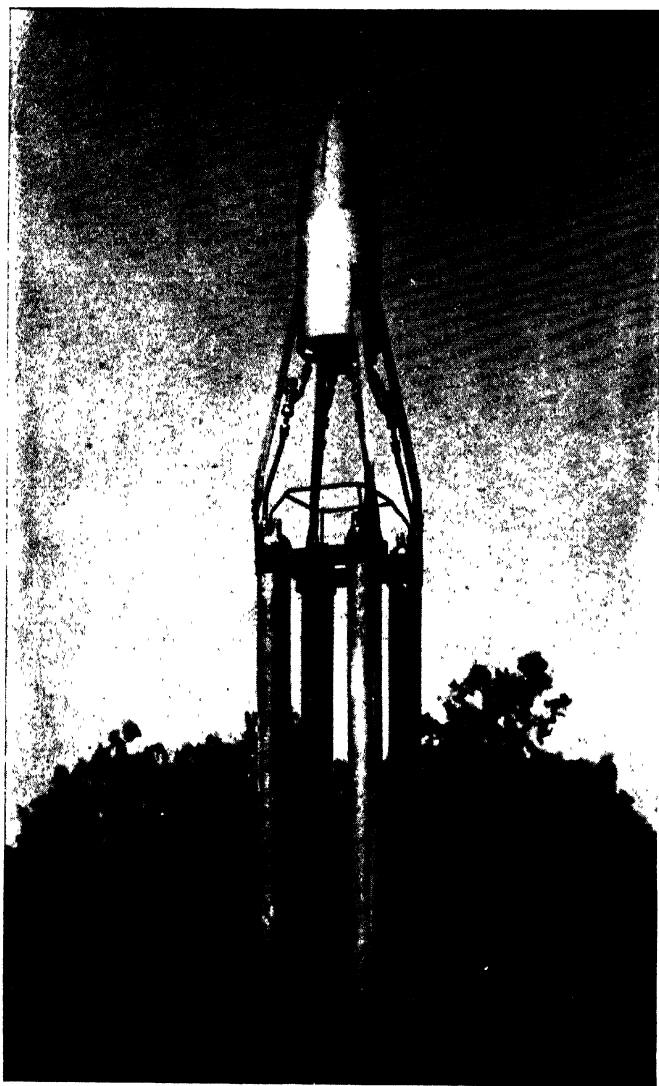
SCIENCE SERVICE



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SCIENCE SERVICE

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PARAMOUNT FROM SOVFOTO

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FOREWORD

THIS is a book about rockets and about the idea of interplanetary travel, and I wish to emphasize that these two things belong together. Of course, it is possible to write a book on rockets which does not mention the idea of interplanetary travel; for example, in a treatise on war rockets, their history, methods of manufacture, and tactical employment.

But you cannot write about rocket theory without getting involved with interplanetary travel. Conversely, not even the shortest essay on interplanetary travel is possible without mention of rocket theory.

Because it is my firm conviction that rocket research will lead to the realization of that great old dream and because I see little value in any rocket research which states that it is not supposed to lead to that goal, I have written this book.

Essentially it is the story of a great idea, a dream if you wish, which probably began many many centuries ago on the islands off the coast of Greece. It has been dreamt again and again ever since, on meadows under a starry sky, behind the eyepieces of large telescopes in quiet observatories on top of a mountain in the Arizona desert or in wooded hills near the European capitals. It has been dreamt all over the earth, in places ranging from quiet libraries to noisy machine shops. And everyone who thought about that dream added a little knowledge.

The thought assumed many shapes and facets. It was philosophic wonder whether the earth, and humanity on it, are alone in the universe or whether there are other earths with other humanities. It was astronomical research, trying to establish some knowledge about those other "earths" that were known to exist, the other planets of our sun. It was biological research which tortured the spores of bacteria with vacuum and cold, trying to see whether they would survive. It was an engineering problem, clothed in symbols and equations.

Because the story of that idea has so many facets, it deals with many different things and many different kinds of people. It deals with old philosophers who thought in Latin, it deals with well-trained modern astronomers measuring Angström units on a spectrograph, with inventors sketching lofty designs on scratch pads.

It finally deals with engineers crouching in a dug-out some twenty-five feet away from a roaring flame which at any instant and without warning may charge into an erupting geyser of liquid fire and screaming splinters of metal.

It is a story with many ramifications, side issues, and blind alleys. But it is also a story of continuous progress, one small step here and another one there. It is a long story too. First the problem itself had to grow up; men had to realize—and then *prove*—that the luminous pinpoints in the sky were worlds, as large as and usually larger than our own. After that . . . but the book tells the story.

Its main point is to make clear that you cannot, as a popular term unfortunately has it, “fly (or shoot) to the moon.” This is by now an absolute certainty. The atmosphere of the Earth extends for just about one per cent of the distance to the moon, and at best 3 per cent of the height of the atmosphere is suitable for flying: the 3 per cent closest to the ground. To “shoot” to the moon, in the manner employed by the heroes of Jules Verne’s famous novel, is impossible too, although it is not so easy to explain why. At any event, even if it could be done, it would be useless.

But we also know by now that it is perfectly possible, at least in theory, to break away from the Earth and reach the other planets of our solar system, at first, presumably, our own moon. And we know that a ship which could accomplish this feat would have to be operating on the principle of Newton’s Third Law of Motion. The best known embodiment of that law is the rocket.

But rockets, and this is important, are not “shot” and they do not “fly.” They are “fired” (meaning ignited), and no initial motion is supplied to them; they do all their own propelling from that moment on. Rising, they do not “fly”; they cleave the air more or less in the manner of a projectile.

To those who do not believe in theory, Army tests with the V-2 have shown that a rocket can rise to 114 miles. Such a rocket is merely the beginning; rockets to higher altitudes will follow. And, one day, the altitude will be such that it will have to be called “distance,” in the sense in which astronomers speak of distance. That will be the (presumably unmanned) space rocket.

And the spaceship will follow after that, one day in the future. Possibly in a future not too distant.

WILLY LEY

Washington, D. C.

Rockets and Space Travel

THE FUTURE OF FLIGHT BEYOND
THE STRATOSPHERE

Chapter 1:

THE BEGINNINGS OF AN IDEA

There are four several ways whereby this flying in the air hath been or may be attempted. Two of them by the strength of other things, and two of them by our own strength. (1) By spirits, or angels. (2) By the help of fowls. (3) By wings fastened immediately to the body. (4) By a flying chariot.—Bishop John Wilkins in Mathematicall Magick (1648).

INVENTIONS rarely have a history. Usually they have two or three—in some cases, even more. In that respect most inventions can be compared with a structure such as the Eiffel Tower. Surging up into the sky of achievement, they rest on several legs which lie astride the border lines of various fields of human thought and require a vast area as foundation.

Thus the invention of one Johann Gutenberg is, or was, the result (better: one of the results) of several histories—of the history of paper and of writing materials, of writing in general, of letter cutting, and several others. There might even be a history of the idea of printing, although here not much evidence is available.

Similarly the idea of space travel, of trips away from the earth, has more than one history. The history of astronomy and astronomical thought contributes much material, especially those parts dealing with the twenty centuries of philosophic battle over the concept of a “plurality of worlds.” But, while the idea of space travel was identified for a long time with the “plurality of worlds” concept, the full stories of these two ideas are by no means identical. The history of the art of making powder rockets furnishes another line in the development of the concept of space travel, as does the history of certain physical laws, most especially Sir Isaac Newton’s Third Law of Motion and Johannes Kepler’s three laws governing the motions of the planets. Even the history of fantastic literature goes into the making of this story. Indeed, there seems to be hardly a field of human thought or human knowledge that is not somehow connected with the idea.

Its origin goes back a considerable number of centuries, though

not to the dim days at the twilight of history as some writers on the subject, especially older ones, have asserted. As a matter of fact, it can be dated with considerable accuracy: it sprang up as soon as astronomical thought had attained a certain stage of development. It did not, for example, exist in the days of ancient Babylon.

We know that the Babylonians, by means of patient and long observation of the sky in a favorable climate, possessed an extensive knowledge of the apparent motions of the heavenly bodies. A modern man who, looking out of his window, notices a reddish star near the horizon, may wonder whether it might not be Mars. In thinking that he will remember that Mars is a planet farther away from the sun than the earth, that it is smaller than the earth, and that it takes about two of our years to revolve around the sun. He will wonder whether it might, after all, be "inhabited."

The train of thought of an astronomer-priest of ancient Babylon was different. He would have known at once that the red star *is* Mars, in fact he would have expected it. He would be able to trace its apparent movement across the sky; he would know after how many months and days it would reappear and where.

But Mars, to the priest, would not be the next planet outside the orbit of the earth, having about two-thirds the diameter of the earth and moving along its orbit at a steadily varying distance. Mars, to the priest, would not even be a solid body. To him it would be the abode of a certain god and his knowledge of that abode, as well as his *duty*, would consist of knowing the star's movements. Nothing else. There is not the smallest indication that the Babylonians, who possessed a patiently acquired and enormous knowledge of the movements of the sun, the moon, and the planets among the so-called fixed stars, ever attempted to determine their distance or their properties. It may be that they felt that such inquiries should not be made about the abodes of the gods; at any event, they never tried. Their astronomical knowledge was extensive and surprisingly reliable as far as the apparent movements of the lights in the sky went. Aside from that their astronomical knowledge was nil and their conceptions were childish. The absence of the idea that there were other worlds, somehow comparable in size to the size of the earth, precluded all further knowledge.

Ancient Chinese astronomy exhibits the same limitation. The ancient Chinese astronomers, again by patient observation, learned to recognize certain cycles. They knew what lights would be in the

sky at what time and where. They predicted eclipses. They even invented a number of astronomical instruments—not telescopes, but instruments that are a great help in ascertaining the position of a planet or a star. But they believed that the earth was flat and they did not even guess that the lights in the sky which they observed so diligently might be other worlds.

It was left for the Greeks to invent better concepts, concepts which coincided to a large extent with reality and served as a starting point for future development.

Greek astronomy began to go its own ways about 540 B.C., a century after a Babylonian astronomer founded a school on the island of Cos. The most important "secret" the Babylonian taught was the so-called *Saros*, a cycle of 223 lunations or eighteen years and eleven days. After one such period the moon returns almost precisely to its original position in the sky. The knowledge of this period, of the *Saros*, permitted the making of astronomical predictions—the prediction of an eclipse, among other things. It was one of the first instances of a prediction that was not a prophecy—that is, something which may or may not come true—but a calculation giving exact information about the future. Thales of Miletus, who died in 548 B.C. and who is often called the Father of Greek Astronomy, may have been a pupil of that Babylonian.

Later, as the *Encyclopedia Britannica* has it:

Pythagoras of Samos (fl. 540-10 B.C.) learned on his travels in Egypt and the East to identify the morning and evening stars, to recognize the obliquity of the ecliptic and to regard the earth as a sphere freely poised in space. . . . Heraclides of Pontus, who became a disciple of Plato in 360 B.C., taught in addition that the sun, while circulating around the earth, was the center of revolution to Venus and Mercury.

The Greeks almost succeeded in arriving at a true picture of the solar system; Aristarchus of Samos actually proposed what we now call the Copernican system, with the sun in the center and the planets revolving around it. The same Aristarchus tried to measure the relative distances of the sun and the moon from the earth. The attempt miscarried, partly because of the lack of magnifying instruments for observation, partly because his method was not quite adequate.

Six years after this attempt Eratosthenes was born at Cyrene.

He became a famous philosopher, so famous that Ptolemy Euergetes called him to Alexandria. He was given the post of Royal Librarian at Alexandria, the center of the cultural and intellectual life of the time. Eratosthenes decided to measure the earth. He did, and he found a figure surprisingly close to the truth. He had succeeded in establishing the size of the earth a little over two centuries before the birth of Christ.

The next great astronomer was Hipparchus who lived from about 180 B.C. to about 125 B.C. Hipparchus carefully verified a number of Babylonian discoveries that had to do with apparent motions; he determined the length of the year, the obliquity of the ecliptic, and many other things on the same order. His most important work was the cataloguing of 1080 "fixed" stars—he divided them into six magnitudes according to their apparent brightness, a system which is still in use.

These were great and valuable achievements but Hipparchus marred them, at least in our eyes, by making the bad mistake of discarding Aristarchus' correct conception of the sun as the center, or approximate center, of the movements of the planets. Eratosthenes' measurement of the earth may have frightened him—this was too big a globe to set in motion. Thus Hipparchus gave way to the emotionally and geometrically easier system of placing the earth in the center and of letting the planets, including the sun and moon, revolve around the earth.

This is what is usually called the Ptolemaic System, but Claudius Ptolemaeus, after whom it is named, did not invent it. Claudius Ptolemaeus, who came some 250 years after Hipparchus, rounded out the work of the earlier master. The result of this work was a book which preserved "the Hipparchus" for us, all the more important since only one early work by Hipparchus survived in its original form. The book by Claudius Ptolemaeus was called the *Mega Syntas* (Great Collection). Some seven hundred years later an unnamed translator was called upon by the astronomically inclined Caliph al-Mámun to translate it into Arabic. The translator did and, using the Greek word *megiste* (greatest) with the Arab prefix *al*, gave to it the title under which it has been known ever since: the *Almagest*.

While astronomy developed in this manner, philosophic commentary and speculations had not been idle. One of the main prob-

lems was what size and what constitution should be ascribed to the heavenly bodies. That question might never have come up, if it had not been for the sun and the moon, especially the latter.

The stars might seem to change their positions in the sky if one traveled in a north-south direction; the *planetes* (wanderers) as the Greeks called them might follow their own mysterious courses. Hesperus and Phosphorus (Venus) might shine so brightly that they made objects cast a shadow, but the stars and the planets and even Hesperus and Phosphorus were only luminous points in the firmament. The sun and the moon were more than luminous points; they had a definite size. Now the sun was obviously a searing fire—or, as later ideas went, the reflection of such a fire—but the moon had to be something else.

It looked, but for its spots, like a round shield of pure silver and, at a time when the earth was still thought to be flat, it was taken for just that. But there was a divergence of opinion as to the nature of those spots. One school of thought held that they were dirt—soot from the atmosphere of the earth, smoke, or fog that had condensed itself on Selene's shiny silver disk. Another school of thought held that the silver disk was in itself spotless and that those spots were just a reflection of land and water on the earth, that in studying the spots of the lunar disk you were really studying terrestrial geography.

We don't know just who held these opinions and when—they have been preserved for us by Pliny the Elder—but they must have preceded Thales of Miletus who discarded the silver disk theory and ascribed an "earthly nature" to the moon. If he actually did say that, he might have startled his listeners as much as Anaxagoras, somewhat later, startled the Court of Pericles by asserting that the sun might, after all, be larger than the whole mainland of Greece. The same Anaxagoras is also said to have asserted that "there are dwellings on the moon, and it contains hills and ravines." Since sun and moon are of the same apparent size, Anaxagoras probably believed that the moon also was somewhat larger than the whole mainland of Greece, and a "country" of that size would, naturally, be roomy enough for hills and ravines and rivers with dwellings on their banks.

One school of thought, however, went farther: the Pythagoreans. In order to bring the number of wandering celestial bodies to ten, a figure "holy" to the Pythagoreans, they invented the *Antikthton*,

the counter-earth. It was supposed to follow the same course around the "central fire" as the earth, having, like earth, an "uninhabitable hemisphere," namely, the one turned toward the "central fire." (The sun was only a reflection of that fire.) Since this assumed body was a counter-earth, it seemed likely that it was a counterpart of the earth in every respect, including inhabitants.

But the counter-earth was accepted only among Pythagoreans, not generally. Widespread belief in inhabited or at least inhabitable worlds centered mainly on the moon.¹ Flammarion and Linke, on the other hand, wrongly claimed that this belief was held for all the planets in general by early Greek philosophy.

The one man who definitely opposed all these speculations was Aristotle. It was only one of his many and often rather stupid mistakes to reject the idea of a "plurality of worlds." The unchanging sky, he stated, prevented the belief in other earths. Since all matter is contained in one world there can be no others and, since earths are heavy, they *must* come together in the center of the universe. Like Plato, Aristotle rejected both infinity and plurality.

Aristotle's attitude, in this and in other respects, would have handicapped science much less if he had not been so wholeheartedly accepted by Christian teachers a thousand years later. It literally came to the point where thinkers set out with the notion that all wisdom could be found in the Bible, all astronomy in the *Almagest*, and all science in the writings of Aristotle. Not only was it simply forbidden to teach anything that contradicted or diverged from Aristotle's statements, it was also denied that there was anything that Aristotle had not known.

But this attitude, which made life difficult for Giordano Bruno, Nicholas Copernicus, and Galileo Galilei, came much later. Those

¹ "More current than the conception of an inhabited counter-earth was the belief that the moon is similar to our globe. Orpheus describes it as a 'celestial earth,' Thales is said to consider it of an earthly nature, and the Pythagoreans are recorded as believing 'the moon is terraneous, is inhabited as our earth is, and contains animals of a larger size and plants of a rarer beauty than our globe affords. The animals in their virtues and energy are fifteen degrees superior to ours, emit nothing excrementitious, and the days are fifteen times longer.' Philolaus considers the moon 'a body like the earth, with plants and animals,' and Xenophanes thinks of it as 'inhabited, and a land of many cities and mountains.' To Anaxagoras and Democritus it is 'a solid, condensed, and fiery body, in which there are countries, mountains, and valleys.' Heraclitus regards it as 'an earth covered with a bright cloud.'—Dr. Grant McColley in *Annals of Science* (1936), Vol. I, No. 4.

who came soon after Aristotle considered him but one philosopher among several and they felt that they had learned a great deal since the time of his death.

Metrodorus remarked rather simply that "it seems absurd that in a large field only one stalk should grow and in infinite space only one world exist." And Plutarch poked fun at the notion that the earth should be situated in the middle of the universe, since the universe was infinite and without boundaries, hence also without a center. This same Plutarch, who is still well known in our times as author of the *Lives*, wrote a book *On the Face That Can Be Seen in the Orb of the Moon* (*De Facie in Orbe Lunae*).

It was a great summary of all the earlier ideas and thoughts and Plutarch emerged with the conviction that the moon is a second earth. Slightly smaller, yes, but very much like the earth in other respects. Of course it is inhabited—by the souls of the dead. This is a new thought and probably Plutarch's own. To us the thought of a world inhabited by the souls of the dead is apt to have some rather eerie connotations, but Plutarch probably wanted it to be taken as a matter-of-fact statement. I doubt whether it was meant as a weird fantasy.

The existence of Plutarch's book shows that in his time at least the moon was generally accepted as a solid body in the sky. The true nature of those luminous pin points might be debatable, but there was at least one other "earth." The fundamental conception necessary for the growth of the idea of space travel, that of other worlds besides our own, had been established.

Plutarch died in A.D. 120. Precisely forty years later the first novel of a voyage to the moon was written. Its author was the Greek sophist and satirist, Lucian (properly: Lukian) of Samosata.

Lukian called the book *True History*—it is often referred to under its Latin title *Vera Historia*—but warned the reader at the outset: "I write of things which I have neither seen nor suffered nor learned from another, things which are not and never could have been, and therefore my readers should by no means believe them."

The story itself, which was to exert great literary influence some fourteen centuries later, is the "missing adventure" of Odysseus—an adventure that could have been in the *Odyssey* and which, I believe, would have been in the *Odyssey* if the necessary astronomical knowledge had existed in Homer's time.

The *Vera Historia* begins with a number of adventures which still

take place on earth, but in that strange and unknown region west of the Pillars of Hercules, west of Gibraltar, where adventures of incredible nature seemed the rule rather than the exception. It seems that the Phoenicians in their time had invented and told gruesome tales of that region in wholesale lots, presumably for the purpose of frightening possible competitors away from the West and especially from the Atlantic Ocean. These tales also enabled them to drive harder bargains for their trade goods; wares that had been acquired with so much personal danger naturally commanded higher prices. In Lukian's time many of these old tales were still lingering, at least to the extent that they could be used for literary purposes, even though they no longer frightened sailors and traders.

After these preliminary adventures, when the reader might expect that the vessel is ready to sail for home, the great adventure strikes. The ship is caught in a terrible whirlwind and lifted out of the sea. The wind carries it high above the ocean and for seven days and seven nights the travelers do not know what is going to happen to them. But on the eighth day, as the first English translation (Oxford, 1634) has it: "wee came in view of a great countrie in the aire, like to a shining Island."

The ship has reached the moon.

The travelers are soon surrounded by warriors riding on three-headed gigantic birds and are brought before the king who greets them in classic Greek since he is Endymion himself. The travelers are sufficiently astonished by this, but they are even more astonished when they learn that the moon is on the brink of a war with the sun. Both sides have prepared extensively for this war and both have acquired Allies so that their armies are very impressive. The infantry alone numbered 60,000,000 men. Then there were 80,000 men of the aerial cavalry, riding the three-headed birds, and 20,000 cabbage-bird riders, having mounts of enormous size covered with a dense growth of cabbage deep enough for a man to hide in. There also were giant spiders, the smallest of them larger than an island, there were garlic throwers, flea riders (30,000 of them), and gigantic ants, the latter in the army of the sun.

Lukian's satirical mind must have worked overtime when he invented these armies and their components, and outside the narrow globe of the earth he found real opportunities for enthusiastic satire. He seized upon anything he could find. Remember those ideas about the inhabitants of the moon who do not eject anything excre-

mentitious? Lukian took that, but he went farther. Of course they did not die either since death, even the most decorous death, cannot help but be somewhat messy as an aftermath. Lukian's selenites don't die at all, nor are they immortal. When their time comes they dissolve into vapor and smoke, a quiet and terribly clean exit from life. Nor do they indulge in sex, as far as one can find out, nor in childbirth of the terrestrial variety. Being ultra-ultra in every respect, just as the old philosophers had demanded, the young one emerges with enormous cleanliness.

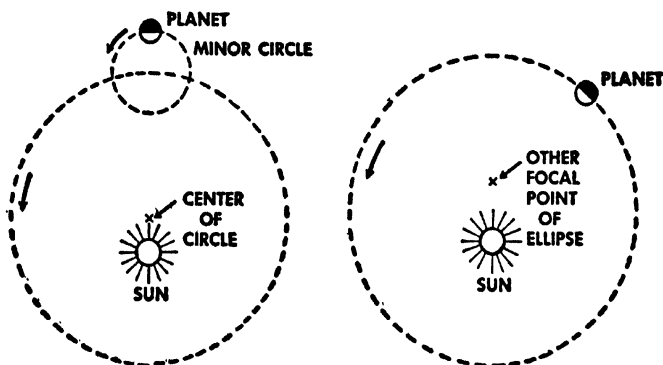
While the travelers of the *Vera Historia* made their trip to the moon accidentally, the hero of Lukian's other moon-travel story, *Icaromenippus*, plans his trip carefully. Observing the night sky for a long long time, and wondering about the matter that composes the radiant sun but being especially attracted by the moon, Lukian's second hero finally decides to go to the moon and to the stars. He provides himself with two wings, one of a vulture and one of an eagle, and begins to practice. He does learn how to fly and when he feels sure of himself in the new element he takes off for the moon from the summit of Mt. Olympus.

He does reach the moon, but that alone does not satisfy his curiosity. Now that he has gone so far, he strives to reach heaven itself. Taking off from the moon and leaving the sun to his right, he flies about among the stars and he arrives in heaven on the third day of that flight.

But the immortals resent the intrusion. Mercury is ordered to bring him back to earth and, while Icaromenippus is not punished for his audacity, his wings are taken away from him so that he may not reach the moon and the stars again.

For more than fourteen centuries no other book like Plutarch's *De Facie in Orbe Lunae* or Lukian's *Vera Historia* was written. For more than fourteen centuries no such book could be written, because philosophical teachings which opposed the idea of a plurality of worlds held sway. Once more the earth was flat and, even if it was not flat, it was the only solid globe. No other earth, no other world existed officially. For a time belief in other worlds than ours was expressly forbidden.

But then the astronomical revolution came, ushering in a new era of astronomy. That revolution consisted of three books: Nicholas Copernicus' *De Revolutionibus Orbium Coelestium*. (On the

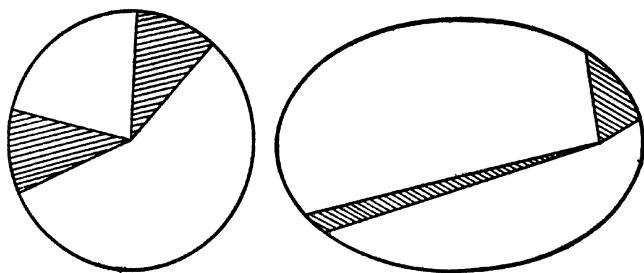


1. Copernicus's Picture and Kepler's Picture of Earth's Movement around the Sun.

Revolutions of the Celestial Orbs) in 1543; Johannes Kepler's *De Motibus Stellae Martis* (*On the Motions of Mars*) in 1609; and Galileo Galilei's *Sidereus Nuncius* (*Messenger of the Stars*) in 1610.

Each one of these books was of almost incredible importance, even when taken separately. Together they formed, in logical progression, a new picture of the world. Copernicus reversed the positions of sun and earth, placing the sun in the center and the earth among the planets, but his mechanism of movement was still the same as Hipparchus'. Kepler changed the mechanism; he replaced the circle on a circle by the elongated curve of the ellipse. This was the first of his "three laws"—the law that planets move in an elliptical orbit with the sun in one of the two focal points of the ellipse. The second law stated that the *radius vector* (the line connecting the center of the sun with the center of the planet) sweeps over equal areas in equal times. This meant that the planet, when closest to the sun, moves fastest, and moves slowest when farthest from the sun. (Fig. 2.) The third law, which he discovered later, dealt with the relationship between the distances of the planets and the amount of time needed to complete one full revolution around the sun.

Copernicus and Kepler put the mechanics of the solar system in order. Galileo Galilei, by means of a homemade telescope which he had virtually invented himself (after studying the principles on which the first "miracle tube," invented by the Dutchman Jan Lip-



2. Kepler's Second Law.

pershey, was based), put worlds into the solar system. He discovered that all the planets show disks when seen through the telescope and this proved that they were worlds comparable to the earth and the moon, even though they all differed in size.

Because of the fact that astrologers and philosophers of the old school succeeded in using the powers of the Church for their own ends, Copernicus' *De Revolutionibus* was put on the index of forbidden books in 1616 where it remained until 1835. Galilei was forced to recant—and the rapid development of astronomy in the next two centuries originated chiefly in Protestant countries.

In these countries the new developments in astronomy (based on the existence of the telescope), a revived interest in the problem of the plurality of worlds, and even a decided interest in the idea of space travel grew up hand in hand.

It began with a work by one of the great masters himself: Kepler's *Somnium*. This work cannot be dated accurately, because Kepler did not write his *Somnium* at any specific time. The book is the result of idle moments or, possibly, periods of sickness covering many years of his life. There is reason to believe that several hand-written copies of the manuscript existed, and one of them seems to have found its way to England. But Kepler hesitated to have it printed; he never considered it quite finished and ready for the printer. In 1630 Kepler died, not quite sixty years of age. Death came suddenly, in the form of an attack of pneumonia which he contracted while traveling long distances over poor roads and in bad weather, trying to collect debts long overdue. The *Somnium* was still not quite finished then and Kepler's son-in-law, Professor Bartsch, undertook the task of making it ready. But then Bartsch

also died suddenly and the manuscript fell into the hands of Kepler's son Ludwig.

Ludwig considered it his duty to "leave to posterity the fame of my father without lacunae" and Kepler's heirs, impecunious as they were, shared the expense of the printing.

The *Somnium* is a fantasy, a fantasy with the little sad smile of a man whose good sense of humor is somewhat incapacitated by physical pain. It is full of interesting side lights, little humorous thoughts about Tycho Brahe, the garrulous, boisterous, conceited creator of the observatory of Uraniborg, the drunkard whose nose was made of silver (the original having been lost in a youthful brawl), the ox-strong nobleman without a home, the man who made the best and most reliable observations anybody ever made up to his time—observations that enabled Kepler to throw out the artificial circles of antiquity and of Copernicus and substitute his own ellipses. It is also tinged by Kepler's own desire for sleep and rest and it shows influences of the enforced restlessness of a Protestant in those times. "If they finally chase us from the Earth," he wrote in 1629 to a friend, "my book will be useful to emigrants and pilgrims as a guidebook of the moon."

The *Somnium* begins with Kepler lying in bed, asleep, resting from incessant labors over sheets filled with computations. Soon he is dreaming. He dreams that he has bought a book in a bookstall and is now reading it. That book tells of an Icelander who made the long pilgrimage to Tycho Brahe to learn what astronomers know about the moon. After several years he returns to his native island of glaciers and boiling springs. He finds his mother who spends her time in collecting strange herbs—a witch, as the son now realizes. He tells her about Tycho and his teachings and he learns, to his utmost surprise, that his mother knows much more about the moon than all astronomers in the world taken together. She has had a better teacher than her son, because her teacher is a demon—a demon from Levanía.

It becomes clear immediately what "Levanía" is; the demon himself provides the clue in the first sentence he speaks: "*Quinquaginta millibus miliarium Germanicorum in aetheris profundo sita est Levanía insula*" ("Fifty thousand German miles away in the deep ether there is the island of Levanía").

Levanía is not inaccessible, but there are certain difficulties. Little demons are rampant both on Levanía and on Volva (the

earth). But they shun the light of the sun and they cannot cross space because the rays of the sun would catch them there. They cannot cross space, that is, under ordinary circumstances. But when the shadow of the earth touches the moon, they are able to race across this temporary bridge. And they return when the shadow of the moon touches the earth.

It is clear what Kepler meant. The demons, the spirits of astronomy, must shun the sun's glare, for you cannot observe while the sun is blinding you. The spirits of astronomy thrive during the night when it is dark, and observations that are impossible otherwise can be made when the shadows of earth and moon reach across the void: during eclipses.

The spirits *can* take a mortal along, but it is hard work and it cannot be done at all if the mortal is too big and paunchy. (It seems that Kepler did not trust Tycho's abilities beyond that of making good observations.) Nor is the trip pleasant for any mortal—when the spirits pull him rapidly along the temporary bridge of the earth's shadow, he suffers from cold and lack of air. At the point where the "magnetic influence" of the moon becomes stronger than that of the earth the spirits let go and the mortal will then fall to the moon without their help. But at this point something strange takes place; the body of a mortal will curl up into itself "like a spider." Kepler had seen how certain spiders, when disturbed, pull all eight legs in and let themselves drop. He even explained in more detail what he meant: "When the magnetic attractions of the moon and of the earth equalize each other, it is as if neither of them exerted any attraction. Then the body itself, being the whole, attracts its minor parts, the limbs, because it is the whole."

Erase the word magnetism and you have a description of gravitational effects, long before Newton. As a matter of fact, Newton merely reported in sharp and clear language what Kepler describes in a playful mood, and I have often wondered whether Kepler may not have had such a sharp description with formulae somewhere among his notes.

As soon as the spirits arrive at the moon they hide in dark caves, knowing that the sun's rays will beat down upon the moon again at any moment. This, Kepler added, is a habit of astronomers too. "When I lived in Prague I had an apartment where there was no better place to observe the sun crossing the meridian than the beer cellar."

At this point Kepler stops playing. We now are on the moon and the astronomy lesson is about to begin. The *Volva* (earth) is large in the sky and the continents and seas are clearly visible. Because of the astronomical fact that the moon always presents the same face to the earth, Levanian is divided into two permanent hemispheres and its inhabitants refer to themselves as *Subvolvani*, those who always have the *Volva* in the sky, and *Privolvani*, those who never see it unless they travel half around their world.

The mountains of Levanian are generally higher and more rugged, the valleys and chasms deeper, than on earth. Since the days and nights are so long, each one lasting fourteen of our days and nights, the temperature differences are enormous. But fortunately there are many caves on the moon and they protect the inhabitants. Besides Nature helps; the bark of the trees and the fur of the animals—or what serves in lieu of fur—comprise the larger part of the mass of their bodies. It does happen that an animal is caught by the sun and seems to drop dead. In that case the outer layer of its fur or skin is singed by the sun and becomes hard. At night the animal revives and the singed portions slough off. In shape the inhabitants of the moon are mostly snake-like; a frequent variety looks like a singed pine cone during the day, while at night the pine cone opens and the animal emerges.

But while the Endymionides, as Kepler terms the inhabitants of the moon, have the shape of strange animals, their mental qualities and capacities resemble that of humans.

Those hollows of the moon first seen by Galilei are . . . portions below the general level, like our oceans. But their appearance makes me judge that they are swampy for the greater part. It is there where the Endymionides find the sites for their fortified cities which protect them against the swampiness as well as against the heat of the sun, possibly also against enemies. They do it in the following manner: in the center of the chosen site they put a stout pole to which they attach ropes, their length depending on the size of the fortress to be built; the longest [rope] measures five German miles [about twenty miles]. Then they mark the periphery by walking around at the end of the rope. After that they amass to build the wall. . . . Whenever the inhabitants feel annoyed by the power of the sun those who live near the center move into the shadow of the outer wall . . . following the shadow for fifteen days they wander about and by this means endure the heat.

The new telescopic era which dawned during Kepler's lifetime shows in this description. Through the new "optick tube," crude and poor as it was, astronomers had now seen the round "craters" in the moon and Kepler, like everybody else, had wondered what caused them. This was his answer: the circular craters were artificial, they were erected by the inhabitants of the moon for the purpose of producing shaded places in which they could keep alive.

Kepler had read Lukian, but the influence went hardly farther than giving rise to the term Endymionides. Of course Lukian had not been serious when he invented his astonishing array of incredible creatures in the army of the moon. But Kepler was serious, in the sense of making a serious guess, and the biological features he invented surpassed the biological knowledge of most biologists of his time. As far as mathematics went Kepler was, needless to say, accurate and his conception of gravitational influences was virtually Newtonian. Even the dream device of getting to the moon was realistically conceived.

To Lukian, and also to many writers even long after Kepler, the problem of flying through the air and the problem of journeying to the moon were one and the same. There was nothing but a gradual difference—the trip to the moon was essentially the same as a flight from one mountain peak to another. It was merely a much longer trip, requiring preliminary practice, as explained for the first time in Lukian's *Icaromenippus*.

Kepler knew that it was not the same. To make flying and space travel alike there had to be a common atmosphere to earth and moon, an atmosphere which, probably, was denser near the surfaces of the two bodies, but an atmosphere which extended all the way from one to the other just the same. And Kepler realized what everybody else overlooked, probably without thinking about it at all: that this meant friction. Friction was the one thing Kepler, who had found the true laws of planetary motion, could not use. There could be no friction. Hence there could be no common atmosphere. Consequently man could not fly to the moon, even granting that he could fly at all. The only way out was a device which did not violate the laws of Nature since it was not subjected to these laws. Kepler, just because he had a better conception of the problem than anybody else for centuries to follow, had to use the dream method.

Even before the *Somnium* saw print, an English book had appeared which also dealt with a voyage to the moon. Unlike the *Somnium* that book, the first interplanetary voyage of English literature, saw several editions and translations. The first edition was printed in 1638 under the title: *The Man in the Moone: / or / A Discourse of a Voyage thither / By / Domingo Gonsales / The speedy Messenger*.²

The author of the book was Bishop Francis Godwin, known to students of English literature mainly as the compiler of a voluminous and boring catalogue of English bishops. Bishop Godwin's book, which still affords amusing reading, shows many influences of the *Somnium*, and he must have read a manuscript copy of Kepler's posthumous work. In fact some of the early adventures of the fictitious hero Domingo Gonzales suggest that Bishop Godwin had the German astronomer in mind as a prototype for his hero. If true, it would be a nice little literary joke that the author of one moon journey is used as hero by the author of another moon journey. Taken purely as "literature" the *Man in the Moone* might outrank the *Somnium*; taken as a work mirroring the scientific knowledge of its period it is inferior.

Bishop Godwin was careful in his work. His hero, being a Catholic Spaniard, uses the Gregorian calendar, while the bishop himself still used the older Julian calendar. But Godwin was not a follower of Copernicus. He accepted the daily rotation of the earth around its axis, an old idea which had been accepted and rejected a few score times in the interval between Pythagoras and Copernicus. But Bishop Godwin did not accept the movement of the earth around the sun. Nor did he follow Kepler as regards the action of gravity and the presumed airlessness of the space between earth and moon. He termed the earth a big lodestone, and assumed that the "attractive force" does not reach very high, not much beyond the cloud zone. On the other hand, he stated quite explicitly that the attraction of the moon is much smaller, since the moon itself is smaller. As for the air above the zone of attraction, he described it as especially mild and pleasant, neither hot nor cold, with the

² The French translation appeared in 1648 under the title: *L'Homme dans la Lune, ou le Voyage chimérique fait au Monde de la Lune, par Dominique Gonzales, aventurier espagnol*. The German translation followed soon after under the title *Der fliegende Wandersmann*. A reprint of the first English edition appeared in 1937, in lieu of a tercentenary celebration, as Vol. XIX, No. 1, of *Smith College Studies in Modern Languages*.

miraculous property of preventing the sensations of hunger. But it is full of "devils and wicked spirits"; Kepler's spirits of astronomy return here in a disguised form.

The moon itself is a perfect paradise, and the rigors of climate that Kepler described are not affirmed. It is a place without want, unrest, or war. The inhabitants are humans, but tend to be of larger size than earthmen. Larger size denotes higher rank and, presumably, greater wisdom. Their language is so musical that it cannot be written in letters; notes have to be used and the bishop did not fail to give a few samples.

The trip itself is a flight. Domingo Gonzales, the hero, finds a "certain kind of wild Swans" which he calls *gansas* on St. Helena and trains them to carry weights and to obey orders. Finally he builds an "engine," which means a seat for himself, carried by a number of *gansas*. Still he only intends to fly, and the trip to the moon comes somewhat as a surprise. The birds fly in the direction of the moon in a straight line, as if it were the place to which they migrate every year. Their speed is great; Domingo estimates it as 50 leagues, about 175 miles, every hour. The flight takes twelve days—but twelve days at that rate of speed is only about 50,000 miles, about one fourth the actual distance to the moon. Godwin probably wanted to arrive at the figure fifty thousand given by Kepler, but he either overlooked the specifying *germanicorum* in his copy of the *Somnium*, or else the copyist had omitted the word.

The return trip back to earth—Domingo happened to land in China—was made in the same manner as the ascent, after enough time had been spent on the moon to make the *gansas* eager to fly back.

If Bishop Godwin's book influenced literature, especially English literature, it shared that influence with another book by another English bishop, which appeared within a few months of the first edition of the *Man in the Moone*. This was Bishop John Wilkins' *The Discovery of a World in the Moone: or, A Discovrse Tending to Prove, that 'tis probable there may be another habitable World in that Planet*.³ This was not fiction, or a discussion disguised as

* The French book *Le Monde dans la Lune, divisé en deux Livres: le premier prouvant que la Lune peut être un Monde; le second que la Terre peut être une planète*, Par le Sieur de la Montagne (Rouen, 1655), is the same, but Wilkins' name is not mentioned. Another French edition appeared in London in 1640, a German translation in 1713.

fiction. It was a straightforward work on the moon, its similarity to the earth, and the possibility of its inhabitation.

Two years later he added to the third edition of this work "The Discovery of a New World," a final chapter in which he seriously affirmed that it was possible to make a flying-chariot, wherein several men might sit, and, by means which he felt science would soon discover, might so motivate their ship that it would fly to any height and might at last reach the moon. His words were a stimulus to both science and literature and his influence in the Royal Society led that great body to turn its attention to the principles lying behind the flying-machine.—Marjorie Nicolson in the Introduction to *Navis Aeria* of B. Zamagna.

It seemed as if the good bishop's optimism was soon to be justified. Not even half a century after the first appearance of his *World in the Moone* the "flying chariot," the airship, was actually invented, though only on paper at first.

The inventor was a Jesuit priest who was professor of mathematics at the University of Ferrara from 1677-79. His name was Francesco de Lana-Terzi and the description of his airship can be found in the second volume of his main work.⁴

Francesco de Lana-Terzi could not have made his invention if others had not worked out experiments which dispelled one of the most unfounded but also most persistent beliefs of older philosophers, the *horror vacui*. "Nature abhors a vacuum" had been handed down like a sacred tradition, just as the other tradition that a body falls faster the heavier it is. That latter tradition had been destroyed by Galileo Galilei, by logic as well as by the experiment of dropping a cannon ball and a musket ball simultaneously from the leaning tower of Pisa and showing that both struck the ground at the same time.

The former tradition had been wounded severely by Torricelli when he invented his "Torricellian tube," the first barometer. Pascal had developed the theory of this instrument; Monsieur Perier, Pascal's brother-in-law, had carried one to the peak of the 4790-foot high Puy-de-Dôme in Auvergne, France, to show that there was less air pressure on mountain tops; and in 1650 the forty-eight-

⁴ Its title is *Magisterium Naturae et Artis*, in three volumes which were published in 1684, 1686, and 1692, the third posthumously since Lana-Terzi died shortly after the publication of Vol. II. (He lived from 1631-87.) The airship appears as *Artificum XLVI* in Vol. II.

year-old burgomaster of Magdeburg, Otto von Guericke, had invented the air pump and demonstrated that a vacuum is possible.

Lana-Terzi presented his ideas in a very logical and systematic manner. First of all he asserted that air has weight. Then he stated that it was possible to exhaust the air from a vessel. He emphasized that the cubic content of a given vessel, say a globe, increases at a much faster rate than its surface area, and arrived at the conclusion: "It is certain that one can construct a vessel of glass or other material which would weigh less than the air contained therein; if, then, one exhausted all the air . . . this vessel would be lighter than the air itself and . . . would float on the air and ascend."

The flaw in his reasoning was of a purely constructive nature; a vacuum globe light enough to weigh less than the air it replaces would be crushed by air pressure. The real solution consisted in substituting a lighter gas for the air inside the globes, thereby eliminating the unmanageable pressure difference—a solution found a few months after the Montgolfier Brothers had built their first hot air balloons in 1783. Professor Charles used hydrogen gas, not known during Lana-Terzi's lifetime, and Bishop Wilkins' "flying chariot" had finally been invented.

But, contrary to all hopes, it could not carry anybody to the moon.

While Perier climbed the Puy-de-Dôme to prove that air pressure diminishes on high mountains, while Otto von Guericke heaped glory on the city of which he was burgomaster by proving that not even several teams of horses could pull two well-fitting exhausted hemispheres apart, and while Lana-Terzi deduced the principle of lighter-than-air flight, philosophers and poets were busy acquainting the world with the rapidly spreading doctrine of the plurality of inhabited worlds and with tales that were based on this doctrine.

Cyrano de Bergerac wrote two novels of that type, the *Voyage dans la Lune* (1649) and *Histoire des États et Empires du Soleil* (1652). Some of it was heavily based on predecessors—the inhabitants of the moon talked music, not words. As for the means of transportation, Cyrano apparently could not make up his mind which should be given preference; consequently several heroes use several means. One is semi-mystical—bottles filled with dew lift the traveler; since dew disappeared in the rays of the morning sun, it was evidently drawn toward the sky. Two others were "flying chariot" devices: one an iron car lifted by means of pieces of lode-

stone thrown upward continuously; the other simply a box with a number of large powder rockets attached to it. Cyrano, by accident and of course without realizing it, had guessed the proper principle—the principle of reaction. But another half century was to pass until Sir Isaac Newton even stated what reaction really means.

Bernard de Fontenelle's *Entretiens sur la Pluralité des Mondes* (*Discourses on the Plurality of Worlds*) followed in 1686 and took Europe by storm. It was issued and re-issued, translated into several languages, and it even conferred upon its author the honor of being asked to take up residence in the palace of the monarch. He accepted and spent his time writing a book on geometry of which he said that it might be fully understood only by seven or eight mathematicians in Europe, he himself not being one of the eight.

The book, although intended to be a popular astronomy, has to be mentioned here because of its strongly speculative character. The leading idea was that every planet has to be inhabited, but by beings with constitutions conforming to their surroundings—a rather modern thought.

De Fontenelle, not handicapped by such trifles as instruments which can measure the surface temperature of another planet or which can tell the chemical composition of the top layers of their atmospheres, had only two things to go by: the temperature resulting from the distance from the sun and the sizes of the planets. As for Mercury, he asserted that the heat is so enormous that there are rivers of molten lead and silver (actually a river of molten lead is the best that temperature would permit). Its inhabitants cannot imagine a world where little discs of these metals can serve as money. Still, the inhabitants of Mercury endure the heat only because the planet spins rapidly around its axis (actually it turns once during its year, behaving with respect to the sun as the moon behaves with respect to the earth) and they enjoy themselves in anticipation of the coolness of the night which is soon to come. In general they are all hotheads and fools and enormously active because of the heat.

At this point de Fontenelle's German translator, Bode, could not help but interpolate: "Very strange! for with us in Berlin we find that great heat makes people lazy and sleepy instead of lively and active."

As for Venus, it is the planet of love, even though its inhabitants are not very beautiful. They have no time for the serious sciences

because their time is taken up by constant flirtations. They do practice music, poetry, and dancing since these arts have their amorous uses. But, de Fontenelle added sadly, they cannot cook, because they live almost exclusively on air.

Mars is passed over and so is Jupiter to a large extent. De Fontenelle is somewhat embarrassed by the fact that the inhabitants of Jupiter, because of the size of that world, cannot possibly know each other, while on small Mercury everybody knows everybody else. However, the inhabitants of Jupiter have telescopes and one day somebody discovers a hitherto unknown small planet near the sun, the earth. "This is reported by their astronomical journal, but the population either does not hear about it or just laughs, the philosophers whose systems would be disturbed decide not to believe it, and all 'sensible people' harbor great doubts about this announcement."

As for Saturn, life is no pleasure because of the extreme cold. A Saturnian, brought to earth, would die because of the heat, even in the Arctic. Because of the cold, the Saturnians are slow and phlegmatic and remain all their lives in the places where they were born, just like oysters.

With Saturn, de Fontenelle had reached the limits of the solar system as it was then known, but he had to add a few remarks about the moon. Mercury and Venus, because of their proximity to the sun, do not need moons and therefore do not have any. The earth has one, Mars again none (the two small moons of Mars were not known until they were discovered by Asaph Hall in 1877), but luminous birds and luminous mountains illuminate the nights on Mars. Jupiter has, of course, its four large moons, and Saturn gets light from its rings. As for our moon, it might not be inhabited *à cause de la rareté de l'air*.

With all his nonsense, de Fontenelle did reflect some recent progress in astronomy. The moon, once loudly acclaimed as a sister planet of the earth, so similar that it might be difficult to tell the difference at first glance, had fallen into disgrace. The main reason for this remarkable and rapid cooling off was the great *Selenographia* of the astronomer, Johannes Hevelius of Danzig, which had been published in 1647. It was the first systematic work about observations of the moon and it abounded with fine and detailed maps, maps which made this world look rather strange and different. The rarity of the air was recognized and there were great

doubts about the water supply. The moon did not look promising any more.

On the other hand the close approach of Mars in 1672 had been used to determine the true size of the solar system. While this was a truly international venture, most of the mathematical work was done by Giovanni Cassini who found, to his amazement, that the distance from the sun to the earth had to be more than 80 million miles (actually it is 93 million miles), which made the solar system at least twice as large as the most daring figures that had been advanced speculatively.

Things had suddenly grown too large, too impressive, for light-headed speculation on actual travel. And it also became clear to everybody what Kepler had taken for granted more than a century earlier: that the atmosphere formed only a thin shell around the earth, that even the possession of a flying chariot did not mean the possibility of a trip to the moon. It is significant that the first great poem on aviation, Bernard Zamagna's *Navis Aeria*, published for the first time in Rome in 1768, abstains from any mention of space travel.

The poem describes the building of an airship of the type invented on paper by Lana-Terzi, but the completed ship stays close to the ground; in fact, Zamagna even warns that it should not fly too high in the atmosphere because the air may become too thin.

Consequently, the two works of this period which deal with inhabitants of other worlds are carefully "non-material." These two works, as different from each other as is humanly possible, are Voltaire's *Micromégas* (1752) and Emanuel Swedenborg's *Arcana coelestia*. Voltaire's *Micromégas* relates the travels of a gigantic inhabitant of Sirius who is later accompanied by an inhabitant of Saturn. It is straight philosophical satire.

To be a philosopher and a satirist at the same time is not at all difficult, but Emanuel Swedenborg succeeded in combining the somewhat contradictory features of research scientist and mystic. As a research scientist he contributed a great deal to various sciences, especially mineralogy and geology. As a mystic he accepted the fundamental theorem that all worlds are inhabited. It seems, of course, that his "astral men" have to be taken "spiritually" which means, in plain language, that they are not to be taken literally. Nor are they very important in themselves; their importance lies in the fact that they prompted Immanuel Kant to devote a very

large section of one of his works to an examination of these beliefs.

The realization that a means of flight was not simultaneously a means of cosmic travel⁵ suggested that the latter would require a new principle, possibly the application of a new force. It is only natural that the vaguely known force of electricity suggested itself.

The same Otto von Guericke who had invented the air pump had also invented an "electric machine," consisting mainly of a large ball of sulphur which could be turned by means of a handle. The experimenter himself furnished friction by placing his hand upon the rotating sulphur sphere, and it was a beautiful toy for drawing room demonstrations and perfumed philosophical discussions with Madame la Marquise.

It was a Frenchman who expanded Guericke's sulphur ball into a spaceship, Louis-Guillaume de la Follie whose *Philosophe sans Prétention* was published at Paris in 1775. But the invention was not made on earth; it took place on Mercury where a young scientist asked for admission to the Mercurian equivalent of the *Académie* on the grounds that he had invented a flying machine. One of the members declared that such a machine could not possibly work and vowed that he himself would use it for a flight to Hermione (earth) in case that he should be wrong and the inventor be right. Of course the machine does fly, and the conservative philosopher, ashamed of his rashness, makes good his vow to fly to earth with it. The trip itself is uneventful, but an irreplaceable part breaks while landing, marooning the Mercurian philosopher on Hermione, the third planet from the sun.

⁵ Edgar Allan Poe's "Unparalleled Adventure of One Hans Pfaall," published in 1835 in the *Southern Literary Messenger*, which uses a balloon as a means of flight to the moon is, of course, in the spirit of banter.

Chapter 2:

THE DECADES OF THE GREAT DREAMS

In fact the two planets earth and Mars are the middle links of the planetary system, and it may be suspected with fair probability of their inhabitants that they stand in the center between the extremes as regards physiology as well as it regards morals.—Immanuel Kant in General Natural History and Theory of the Heavens (1755).

ON NOVEMBER 13, 1833, Sir John Herschel, the son of Sir William Herschel, embarked for Table Bay. He arrived at Cape-town on January 15, 1834, and on March 4 he began the astronomical observations for which the long trip had been made. It was the first systematic attempt at exploration of the southern sky and not only professional astronomers but also the public knew well that Sir John had left for South Africa and why.

On August 25, 1835, the New York daily, *The Sun*, carried a front-page story about the discoveries made at the Cape by Sir John. It was, as may well be stated at the outset, the biggest and most successful scientific hoax ever perpetrated. While purporting to be a reprint from a special supplement of the *Edinburgh Journal of Science*, it had been written in New York by a staff member of *The Sun*, Richard Adams Locke, who by the very invention of this story proved to be a genius in his own right.

The hoax began with an editorial which called the attention of the readers to the first installment of the serialized reprint from the Scotch journal and promised the announcement of astounding discoveries.

But the first installment, contained in the same issue of *The Sun*, did not relate any of these discoveries. It merely spoke of the instrument which had made them possible. Even that, if true, would have been enormously important. In a dignified scientific style it was explained that opticians could easily increase the magnification achieved by a powerful telescope. As far as optics and mechanics go there is hardly a limit, but there exists one annoying fact which renders such an undertaking useless. That fact is that

the image grows weaker the larger it is so that in the end it becomes so faint that nothing can be distinguished any more.

Actually this is only part of the truth. If it were the whole truth concerning the reasons why magnification beyond a certain level cannot be used, the problem would have been solved in the meantime by the invention of the photographic plate which accumulates impressions. The most important reason is that an astronomer on earth has to look through the atmosphere and that this atmosphere is never quiet all the way through. The sickle of Venus is apt to look like the flame of a candle in a draft because of that, and the faint image of a distant star may jump about in the field of vision. The trouble can be remedied somewhat by placing the telescope on top of a high mountain so that the densest and most disturbing section of the atmosphere is beneath, but there is always enough atmosphere left to annoy astronomers and to ruin many nights.

But *The Sun*, or Mr. Locke, went on to say that Sir John Herschel, while discussing this problem with Sir David Brewster, had found a way out. They discovered a method of "transfusing artificial light" into the image and thus brightened it sufficiently to allow for larger magnifications. Just in case some reader happened to see through this fallacy, several paragraphs were devoted to loose talk about microscopic reflectors, angles of incidence, properties of rays, etc., until the reader felt that he could not follow anyway and was, therefore, ready to accept anything he was told. Of course, the story continued, it needed a powerful telescope to begin with, and Sir John Herschel had a 24-foot mirror cast for this purpose. (The 200-inch mirror on Mt. Palomar measures 17 feet.) Theoretically this super-telescope, in combination with the new instrument for the "influx" of artificial light, should be powerful enough to see a butterfly on the moon, provided there were butterflies present.

The second installment described at length the journey to the Cape of Good Hope, the setting up of the telescope, and the observations of some distant stars and star clusters. Then, on January 10 (1835) the huge instrument was directed at the moon. The first thing that appeared on the projection screen was a huge basaltic formation. Everything was as clear as if the observers were floating over the moonscape in a balloon. Then they saw trees resembling yew trees, forests of firs, level grassy plains, and herds of animals. "Brown quadrupeds having all the external characteristics of the bison, but more diminutive." Soon after, another animal appeared

on the screen, of bluish lead color, about the size of a goat, but with a single horn.

The unicorn climaxed the second installment.

As far as business was concerned, *The Sun* had every reason to be exhilarated. It had existed for only two years then, and it was the newspaper with the largest circulation in the world. It sold 19,360 copies, while the circulation of the *London Times* was only 17,000 copies!

The following installments described additional animals and winged bat-like creatures. The latter, when observed more closely, turned out to be the inhabitants of the moon, bat-men and bat-women, flying, sitting around, talking with many gesticulations, and behaving in general rather human.

Later installments told of temples with roofs "consisting of a yellow metal" and the last one wound up with a quick and not particularly inspired survey of the other planets of the solar system.¹

Business remained splendid until the bitter end. A sheet of drawings of the things observed on the moon sold well. A reprint of the whole story in pamphlet form found very willing buyers. But the hoax could not be maintained indefinitely. The first editorial had stated, as did a postscript to the last installment, that the original report continued for another forty printed pages consisting of mathematical data and technical discussions of little or no interest to newspaper readers.

This remark brought Professors Olmstead and Loomis from Yale to New York. They did not blame the editor of *The Sun* for not printing these forty pages, but they were obviously in his possession and they wanted to see them. They were held at bay by Locke who told them to go to the printer. Locke himself raced ahead and instructed the printer where to send them next, racing ahead again, and again, and again, until the professors gave up. Then the *Journal of Commerce* wanted to reprint the whole story and sent a reporter to Locke to get the *Edinburgh Journal*. Locke at first tried to talk him out of reprinting the old stuff, then admitted that he had written it. The next day the *Journal of Commerce* gleefully informed its readers about the truth of *The Sun's* marvellous story.

¹ The complete text of the moon hoax has been reprinted in *The Sky* in several installments, beginning in February 1937 with an introduction by William H. Barton, Jr.

For a while New Yorkers were indignant, then they began to laugh—as did Sir John Herschel who learned about it some time later—and the “Panorama” exhibits and the stage began capitalizing on Locke’s great moon hoax.

It has been claimed that Locke had a collaborator when he wrote the moon hoax, a French astronomer by the name of Jean Nicolas Nicollet who had left his native country because of financial difficulties and who might have been susceptible to a profitable suggestion of that kind. Only Locke himself could have told whether Nicollet helped him or not, but Locke kept quiet about that point. But whether Locke had been helped along by a professional astronomer or not, the moon hoax portrayed better than any learned treatise the general attitude of the public—and of a large number of the scientists—toward the problems involved in that theme.

The nineteenth century had begun with a number of important scientific discoveries and more were confidently expected, an expectation which, as we know now, came true to an almost unbelievable extent. New astronomical discoveries were expected and there was a feeling (well exploited by Locke) that they might follow in the wake of the invention of a new instrument. This also came true in the latter part of the nineteenth century with the introduction of the camera and the spectroscope. Herschel’s “light infiltration” was a guess at what might be invented.

Animals and inhabitants and dwellings on the moon were a guess at what might be discovered, and here again Locke merely expressed a prevalent belief, although the moon was not too well chosen as *locale*. One of the planets, except for its greater distance, might have been more convincing.

The “plurality of worlds” was no longer a matter of dispute. Venus and Mars and the other planets were acclaimed as “other earths,” while the stars were now definitely taken as “other suns,” each one presumably with a system of planets around it. And all the suns together formed the Milky Way, the galaxy. In addition, there was reason to suspect that the so-called nebulae, especially the big one in Andromeda, were other galaxies like ours. Sir John’s trip to the Cape had as one of its main purposes the collection of more data on the existence of these additional galaxies.

But this growth of astronomical knowledge had also resulted, as we have seen in the preceding chapter, in a rather literal “growth” of the universe. The dimensions were now such that even a million

miles were no more than an inch as applied to the dimensions of a city. Astronomers began to use bigger yardsticks. The distance between earth and sun, 93,000,000 miles, was chosen as an A.U. (astronomical unit), and the velocity of light, some 186,000 miles per second, furnished another yardstick. Astronomers began to say that the moon is a little over "one light-second" from the earth and the sun some eight light-minutes, meaning, of course, that the light from the sun needed about eight minutes to reach the earth. But even on that scale the *nearest* star was several light-years away.²

The feeling was that the universe was full of suns, each accompanied by planets most of which were probably inhabited. But all the various inhabitants could do, even those closest to each other in the same solar system, was to look at each other. A vacuum separated them and nothing could bridge it but gravitation, which was unchangingly ever-present and therefore quite useless, and light.

While the nineteenth century became the era of the greatest astronomical dreams, it took some time until it began to dream of direct communication. There were many books and articles on the inhabitants of other worlds, but nobody suggested for quite some time that they might visit us or that we might visit them. The early enthusiasm about the invention of the balloon had quickly changed into disappointment that it could not carry its pilot higher than a very few miles and even that distance with great danger to life and limb because of the cold and lack of oxygen experienced at higher altitudes.

The highest balloon ascent was no more of a departure from the native planet than the distance a fish may jump out of its tank. And it was fraught with the same dangers—suffocation and inclemency. As a matter of fact, the planets began to look like cosmic fish tanks and the various presumed humanities on them like self-contained little worlds in the well-kept tanks. They had been put there by the act of creation and sealed into their particular surroundings. Subject to catastrophes even in their own worlds—Monsieur Cuvier

² In modern astronomy the *parsec* is used along with the light-year. The term means a distance which produces a *parallax* of one *second* of arc, an apparent yearly shift of $1/3600$ of one degree. A parsec works out to 3.259 light-years; it is not much bigger as a unit, but it is more convenient to handle. A light-year is 5880 billion miles.

knew terrible things to tell about such catastrophes—they could do nothing but look out. Dependency on their surroundings forced them to remain at home, and the most they could hope for was to see other fish tanks and guess about those other surroundings.

This was, in approximation, the answer of the year 1830 to the problem of space travel.

But even if those fish could never possibly reach each other, they might—assuming that they had the necessary intelligence—signal each other. In fact this was the way to find out whether the “fish” in another tank were intelligent or not. If they understood a signal and replied to it, they were. If they did not reply, it meant that they did not exist or, if they did exist, that they were not quite bright enough. Of course one had to use a language for the signal which could not possibly be misunderstood, a language in which there was only right or wrong, but no misunderstanding.

It was, of necessity, the language of mathematical symbols, for example, the figure known as the “Pythagoras”—the figure which expresses the fact that the square of the longest side of a right-angled triangle is equal in area to the sum of the squares of the other two sides. If this figure were produced on earth on a scale large enough to be seen from another planet, intelligent beings of that other planet—provided they existed and provided they were intelligent enough to know elementary geometry—would know about humanity, and they would reply in a similar manner.

The Siberian tundra offered a “blackboard” of sufficient size. To “draw” the symbols was a job for farmers and foresters. The outlines would have to be planted in dark pine forest, each line 10 miles wide. And for contrast the interior of the triangle and of the three squares could be seeded with rye or wheat.

This was not a crackpot’s idea; it was Karl Friedrich Gauss, the “Prince of Mathematicians,” who advanced it.

And Littrow of Vienna, a name well known to any astronomer, professional or amateur, followed up with another similar idea. Use the Sahara as a blackboard and use large fires for signs. Arrange them in a circle, for example. Dig a circular trench several hundred yards in width and 20 miles or so in diameter, fill it with water, and pour kerosene on the water, enough kerosene to burn for six hours. Then ignite it. Use a quadratic trench the following night and a triangular trench the night after. This regular succession of regular mathematical symbols ought to convince the inhabitants

of the nearest planets—convince them not only of our intelligence, which grasps the mathematics of simple figures, but also of our intentions to give signs to them since we would never need flaming signs of that size for teaching our own kind.

While Gauss and Littrow evolved these schemes for signaling the other planets, other astronomers frantically searched for signs they might send to us or at least for signs of their existence.

In July 1822 a Munich astronomer with the strange name of Franz von Paula Gruithuisen (*Khroyt-hoyzen*), who was also a somewhat strange man all around, announced that he had found a "walled city" on the moon. It is located near Schröter, a crater almost in the center of the half of the moon we can see. Gruithuisen described it as a regular grid of high walls and drew a picture which looks like a bird's-eye view of a multiple-walled fortress, partly submerged in a flood of mud which later hardened.

The announcement created a stir which can be traced through the whole literature of that time—it is even mentioned in some love stories written around 1830. Any definite building on the moon or elsewhere would be a sensation of the first class. And a kind of fortress would be a solid basis for quite a number of justified conclusions. It would be unmistakable evidence for the existence of intelligent beings, at least the former existence of intelligent beings if you want to be very careful. It would also prove that there is or was another and hostile life form about, presumably intelligent too. It would prove a whole lot of things—provided only that its nature were established.

Gruithuisen's walled city is *not* established. The German astronomer Mädler who, some time after Gruithuisen, produced maps of the moon which remained the best for many decades, drew the famous spot as an irregular pattern of small mountain chains. Modern observations seem to indicate that both exaggerated. The mysterious spot is not as regular as Gruithuisen drew it. Nor is it as irregular as Mädler made it out to be. At any event, it is something for which we don't know a counterpart on earth. If it is not a work of intelligent beings, there is no natural form on earth which is strictly comparable.

Nor, it may be added, do we have anything on earth which is comparable to the Great Valley of the Lunar Alps, or to the 70-mile long Straight Wall near the crater Thebit in Mare Nubium. As for the Great Valley, the only possible explanation is that it

was caused by a very large meteorite, grazing the surface of the moon, while the Straight Wall, also called the Railway, is presumably a rocky fault, with one ledge higher than the other. The fact is that we don't have such things on earth. We don't have such a valley at all and our rocky faults are not only much smaller but also not as straight. Which, when applied to Gruithuisen's "walled city," means that the mere fact that no comparable natural form exists on earth does not imply that the lunar form has of necessity to be man-made.

The same Gruithuisen also found "life on Venus" in rather extreme manifestations. But before we go on to this, we must mention what is probably the wildest astronomical hypothesis ever advanced.

After Hevelius, as we have seen, the moon gradually fell into disrepute as an inhabited planet. The steadily improving telescopes left no doubt that there were no clouds on the moon. The darker areas which had been called *maria* (seas) with early enthusiasm, turned out to be just darker and generally smoother areas. They might still be the bottoms of old seas—although even that is by no means sure—but they certainly were not seas any more. There was, in short, no water on the moon. And there was no air to speak of; when the moon's disk covered a star that "occultation" occurred precisely at the proper second. If the moon had an appreciable atmosphere there would be a delay. Without air and water there could be no life as we know it. The lunarians, or selenites, or endymionides, if they ever existed, belonged to the past.

The nineteenth century made an attempt to "save" them.

The moon, by turning once around its axis while moving once around the earth, succeeds in keeping its opposite hemisphere permanently hidden from the interested eyes of our astronomers. That is, the moon almost succeeds, because there is a slight wobble known under the technical term of libration which permits seeing small portions near the rim on occasion. By accumulating such observations astronomers have succeeded in seeing about four-sevenths of the lunar surface. But the remaining three-sevenths simply have never been seen, nor can they ever be seen by observers stationed on earth.

Now the motion of the moon is peculiar, in fact it is one of the really difficult problems of mathematical astronomy. For a while it seemed as if the evidence pointed at a very peculiar solution. It

seemed that the moon was not spherical as all other planets are—spherical, that is, within the customary deviations from the true mathematical sphere—but egg-shaped. The sharper end of the egg was the one pointing toward the earth, and it seemed as if the visible hemisphere was the enormous bulge of an irregularly shaped body—as if the whole hemisphere we can see, the whole hemisphere with all its craters and maria and mountains, was in itself an enormous mountain.

Then, if that were true, the other side would certainly be greatly different. The waterless and airless moon would be waterless and airless only where we could see it. It would be waterless and airless because it is an enormous mountain. The “back” might resemble earth much more; it might be an enormous tropical jungle with dense and steaming air. It would have to be a watery jungle, it was reasoned, because naturally all the water of the moon would be concentrated on that one hemisphere.

Suddenly it seemed as if this old Pythagorean idea of the “uninhabitable hemisphere” of earth, the hemisphere which cannot be inhabited because it has the “central fire” overhead, were illustrated in the sky. (The uninhabitable hemisphere was, of course, the Western Hemisphere.) The moon seemed to conform to this old fantasy with its enormous bulge sticking out into cold and airless space. From declaring that the other hemisphere was likely to be much more earth-like and inhabitable, it was only one step to saying that it was inhabited.

That hypothesis was never generally accepted by astronomers, but for some time it was an acceptable hypothesis; things *might* be that way. The moon “bubble” was pricked by Simon Newcomb who spent a great deal of his long and busy life investigating the orbital motion of the moon. It turned out that the moon is not precisely spherical, but the difference is too small to matter much. The gigantic earth-pointing “mountain” collapsed and with it collapsed the interesting idea of the watery and inhabitable “other hemisphere.”

Decades later, when the dream was almost forgotten in astronomical circles, it was resurrected for literary purposes by the Polish poet, Jerczy von Żuławsky, in a novel *On Silvery Plains*³ in which the crew of a spaceship from earth sets out on a long trek

³ This is a translation of the title of the German edition, *Auf silbernen Gefilden*. As far as I know there are no other translations of Żuławsky's works.

across the visible hemisphere of the moon to reach the other hemisphere. Some of them succeed and a strange race grows up there, the children of the arrivals from earth.

As a matter of fact, the "other hemisphere" does not seem to differ in any respect from the hemisphere we can see. Certain mountain chains continue "over the rim" and the rims of other maria become visible when the libration is suitable.

If Gruithuisen felt certain of life on the moon—which, of course, meant intelligent life—he was more than certain of life on Venus.

It was well known in Gruithuisen's time that Venus is almost precisely a second earth as far as size and mass goes. But Venus, circling the sun inside the orbit of earth, would be generally warmer. It would be a tropical planet with a vegetation, to use Gruithuisen's own words, "incomparably more luxuriant than even the virgin forests of Brazil."

Now Venus exhibits a strange phenomenon from time to time. The dark parts, the parts where it is night on Venus, are not really dark, but glow with a faint luminosity, reminiscent of the so-called earth-light of the moon. The earth-light of the dark parts of the moon is, as the name implies, caused by the earth; these parts have night as far as their position in relation to the sun is concerned but they are illuminated by the *Volva* in the sky, to fall back on Kepler's name for the earth in the lunar sky. It is possible that the night side of the earth shows a similar faint light to an outside observer when there is a full moon illuminating it.

The very first observers of the Venus light explained it just that way—there was night on Venus with a full moon in the sky. But these first observers had a moon of Venus at their disposal to use for their explanation. We haven't. The "satellite of Venus," seen by several early astronomers, does not exist. We are perfectly certain now that Venus, like Mercury, does not have a moon; those early observers mistook a fixed star for a moon of Venus. There was, consequently, no explanation for the faint luminousness of Venus' night side.

Gruithuisen found one.

Going over astronomical records he noticed that "the principal observations of the ashen light on Venus are those of Mayer in 1759 and of Harding in 1806." There was an interval of 47 years

or of 76 Venus years, an interval which makes no sense whatever from an astronomical point of view.

Gruithuisen agreed with this: "If this period has a religious character we cannot see any justification for that number of years. But," he continued, "it becomes more comprehensible if we assume that some Alexander or Napoleon then attained universal power. If we assume that the ordinary life of an inhabitant of Venus lasts 130 Venus-years, which amount to 80 earth-years, the reign of an Emperor of Venus might well last 76 Venus-years."

The ashen light of Venus, to Professor Franz von Paula Gruithuisen, was the astronomical result of a general festival illumination in honor of the ascension of a new emperor to the throne of the planet. Later Gruithuisen was apparently frightened by his own hypothesis and amended it in saying that it might simply be the burning of large stretches of jungle to produce new farm land—he just missed saying "new *Lebensraum*"—for the growing population of the evening star. "Large migrations of people would be prevented and the resulting wars would be avoided by abolishing the reason for them. Thus the race would be kept united."

To think of a phenomenon like our *aurora borealis* and *aurora australis* in order to explain the ashen light would have been *much* too simple.

It was, of course, difficult to surpass Gruithuisen, but the French inventor Charles Cros did his best. His *Moyens de communications avec les planètes* was published in Paris in 1869. The fact that luminous pin points had been occasionally observed on Venus and Mars—in all probability high clouds which were still struck by the light of the sun while the surface was already in darkness—was sufficient for him to state that the inhabitants of these two planets were trying to communicate with the earth. Cros proposed to answer by means of an enormous mirror, similar to the mirrors used in reflecting telescopes, but many many times as large and of a very shallow curvature.

It was to be so shallow that the focal point was no longer on earth at all but on the surface of the planet with which communication was to be established. If the mirror were large enough to collect a sufficient amount of sunlight, Cros reasoned, and if the focal point of it were near the surface of the Martian desert, the power of the sun's rays would fuse the sand there. Then it would be possible to "write" gigantic figures in the sands of the deserts

of Mars: first simple symbols, like triangles and circles, then more complicated mathematical figures, and finally even simple pictures, the head of a man, the outline of a house, and so on.

Cros wanted the French government to pay for such a mirror and he spent many years of his life making petitions, writing memoranda, and pulling what strings he could. Nobody ever succeeded in convincing him that the existence of the Martians was, after all, not assured. Nobody ever succeeded in convincing him that no optician could build a mirror of sufficient size and precision. Cros stubbornly clung to his idea. He died disappointed and in extreme poverty.

The theme of devising means of communications with other planets has been a recurrent one ever since, although more in the spirit of intellectual curiosity. The German astronomer Plassmann once devoted a paper to the question of whether the Martians could see the light of our large cities. Plassmann wrote it around 1920 or 1925, when cities were much larger and much brighter than in Gruithuisen's and Cros' time. He came to the conclusion that the Martians, provided their eyes were as good as ours and provided that their instruments were as good (and not better) than ours, would never be quite certain whether they did or did not see pin points of light in those spots where terrestrial maps show the names of Moscow, Berlin, Paris, London, New York, Chicago, and Los Angeles. Somewhat better instruments would make that certain.

Plassmann disregarded the Venusians completely in his article and with good reason. Blanketed as they are by their eternal cloud layer, they certainly would not be astronomers and probably would never have invented the telescope. As a matter of fact, it would be easy to "prove" that the presumed Venusians in their presumed environment would not have been able to attain any intellectual level worth mentioning because their environment was not suitable for intellectual development. Intellectual or at any event scientific activity begins with the realization that effect follows cause, that the same cause always produces the same effect, and that there are natural laws. On earth, as far as we can find out, such activity was stirred or at least encouraged by the regularity of certain astronomical features. The moon went through its phases regularly, the seasons repeated regularly, the stars seemed to wander across the sky in a measured tread. The orderliness of the sky suggested orderliness in nature in general and investigation of nature was

begun and finally progressed, in spite of many handicaps in the form of faulty analogies, mistakes, and misunderstandings. Without the starred sky as a starting point nothing like that may ever have taken place.

As for the selenites, if they exist, it may be said that their knowledge of the earth would be large in extent. Again, assuming that their eyes and instruments were as good but not better than ours, their maps of the earth should be excellent. In fact because of their favored position for the observation of the surface of the earth, their maps would surpass our own for a number of sections like some parts of Siberia, of Inner Australia, of Antarctica, and even sections of Alaska and South America. They would know the location of any town of more than a few thousand inhabitants and they could follow the maneuvers of a battle fleet and even of single large liners like the *Queen Mary*.

Some other aspects of interplanetary communication have also been re-examined more recently, of course again in the spirit of intellectual curiosity, not in the form of "projects," even if the newspapers occasionally called them that. An English engineer, for example, calculated the amount of flashlight powder needed to produce a flash that could be seen from Mars, provided the Martians knew where and when to look for it. I don't recall the figure, but it was enormous. Things would be somewhat better if the flashlight powder were not exploded on the ground but raised above the densest layers of the atmosphere by means of captive balloons which rise as high as they can possibly go and are exploded by electric ignition along with the flashlight powder. Under that assumption the figure for the amount needed looked somewhat better but it was still on the order of a trainload.

And finally some people have amused themselves in working out a "letter to the Martians." The purpose of that mental exercise was to find out whether it would be possible at all to establish a mutual understanding with beings of intelligence but of a completely alien race and environment. The "language" would have to be partly pictures and partly mathematics. The letter would begin with a single dot, accompanied by the figure 1. Then two dots accompanied by the figure 2. Then three dots with the figure 3, etc., until the meaning of the figures would be explained. Then the "letter" would progress to simple arithmetic and algebraic operations and to elementary geometry. The meaning of the symbol

of an arrow (direction) would have to be explained and then a picture of the earth could be shown, with an arrow pointing to the picture of Mars. Of course there would be a diagram of the solar system with more arrows drawn in. It seems likely that a message of this type could tell that it came from earth to anybody who can think and see.

All these recent amusements, you may have noticed, spoke about the Martians as an example. This in itself is a modern thought. Around the middle of the nineteenth century Mars was still generally disregarded. It had not yet become important as a planet about which to speculate. If interest centered upon any specific planet it was, thanks to Gruithuisen's efforts, Venus. Naturally such an exciting thought could not fail to leave its mark upon literature and the first novel about a trip to Venus was not long in coming.

Its author was a Frenchman, Achille Eyraud. It was printed in Paris in 1865 and its title was simply *Voyage à Vénus*. Just how much Eyraud was influenced by Gruithuisen is something I'd like to know myself; I never succeeded in laying my hands upon a copy of Eyraud's novel. Wherever I lived I tried the local libraries, but the book seems to be rare. The following description is, therefore, based upon another source: the appendix of a late edition of Camille Flammarion's *Les mondes imaginaires et les mondes réels*.

Eyraud did something from which writers had shied away for more than a century: he "invented" a spaceship for his novel and described its engines. And he must have had a good working knowledge of theoretical physics or else the help of a professional physicist, because he found the only possible means. His ship was propelled by a *moteur à réaction*. Eyraud, according to Flammarion, described the known application of the action-reaction law which then was only the fireworks rocket. He also explained that the recoil of a gun originates in the same manner. And he stated that his *moteur à réaction* worked in the same manner. The remainder of the novel is not important; Flammarion says that on Venus the hero finds a society "hardly different from that of Paris or France." And since his terrestrial fiancée dies on Venus he finally marries *une jeune et belle Vénusienne*.

Achille Eyraud's *moteur à réaction* was important not so much because that writer used the theoretically correct means of accomplishing space travel, but because he was the first to express the belief that science, which had made the whole problem look im-

possible, also produced the means of a solution. If one branch of science had separated the worlds hopelessly by finding enormous distances and airless space, another branch of science pointed out that there were theoretical means of bridging those distances and of braving the nonexisting environment of a vacuum.

Seen from this point of view, Eyraud's novel simply expressed confidence in the powers of science and discovery, a confidence well fortified by the fact that during the preceding half century a number of important discoveries had been made and a number of important inventions had been put to work.

It was the same feeling which produced Jules Verne.

Kenneth Allott, in his excellent Jules Verne biography, has taken great pains to point out that Jules Verne's writings are romantic in sentiment. Of course they are, since explorations of the unknown and possibly also of distant things are by their very nature "romantic." But the more important thing is that Jules Verne represents a new attitude. Consistently his heroes (who are, of course, merely personifications of the scientists, engineers, and explorers of the nineteenth century) do things themselves. They do them in a novel way. They don't do things in a traditional and poor and inefficient manner for the sake of tradition. Nor do they look for "lost arts."

They are not even very romantic; they are mainly truthful. Instead of yielding to the traditional modesty of being "insignificant sons of great ancestors," they act with the full knowledge that their time has surpassed any preceding time. They know that they know more than their ancestors.

They expect their sons to be better than they are and they expect the future to be greater than the present. They don't hesitate to cruise under the seas or to fly through the air. And to them the problem of reaching the moon is what it really is: a question of attaining a sufficiently large velocity in the right direction at the proper time.

Jules Verne's *De la Terre à la Lune* appeared in 1865, the same year that Achille Eyraud's novel saw print. It was a prolific year for that sort of literature. Alexandre Dumas published his *Voyage à la Lune*, Henri de Parville published his *Un habitant de la planète Mars*, an anonymous French author published another *Voyage à la Lune*, an anonymous English writer published *A Journey in the Moon*, and, as if to round out the picture, Camille Flammarion

published his *Mondes imaginaires et mondes réels*, which is essentially a description of all preceding works of literature that deal with astronomy, astronomical philosophy, plurality of the worlds, habitability of the planets, and attempts at interplanetary communication.

The books by Dumas and the anonymous English writer are unimportant. The anonymous *Voyage à la Lune* and de Parville's story are curiously alike in that they begin with the discovery of strange meteorites which are really messages. (Just a few decades earlier Chladni, in his work *Ueber Feuer-Meteore*, had convinced the scientific world that there really was such a thing as a meteorite.) The Mars story is essentially a treatise on the plurality of the worlds, but the *Voyage à la Lune* brings a new thought. It recounts the story of two men who went to the moon to live there. Their trip became possible because they invented or discovered a substance which is not attracted by the gravitational force of the earth but repelled by it.

Jules Verne spent the largest effort in trying to make his method credible. He had decided on a cannon as the proper means of bridging the gulf between earth and moon. He had calculated—and had his calculations checked by astronomical experts—just what muzzle velocity a cannon would have to have to throw a projectile to our satellite. He threw in a number of things then new: the propelling charge was to be guncotton, invented only some fifteen years before by Schönbein; the ball (which was to be large enough to be seen in flight by a new giant telescope) was to be of aluminum which, at that time, was still so rare that chemists made each other presents of little bars weighing a few ounces. In fact the whole book is the story of the preparations for the great event.

The locale of the story is America and the main characters are all members of a fictitious organization, the Gun Club, consisting of gunnery experts who served in and survived the Civil War, although not always complete in their anatomical make-up. The leaders of this club at first only want to send a projectile to the moon in order to show that it can be done. But then a young man by the name of Ardan appears and proposes to be a passenger of the projectile.

Jules Verne had his little joke with that name. Everybody in Paris at once recognized the anagram, Ardan was Nadar and Nadar

was Felix Tournachon, a Paris journalist. "Nadar" had studied medicine, but then turned newspaperman and photographer. In 1852 he had opened a studio in Paris, but his puttering in the dark room did not prevent him from being active in aviation. He built a balloon, the *Géant*, which ascended for the first time in 1863—Jules Verne was in the gondola—and later he built the first of the balloons which left besieged Paris during the Franco-Prussian war of 1870-71. (One of the passengers in these balloons was a man who, as a boy, had almost made the first rocket flight, see page 83.) "Nadar" was also Lesseps' secretary for some time.

Well, Ardan-Nadar compels the Gun Club to revise the plans, the round ball has to be redesigned as an elongated projectile, padded and furnished inside, and equipped with "water buffers" to enable the passengers (they are three, in the end) to survive the shock of firing.

Two years after *De la Terre à la Lune* followed *Autour de la Lune*, the story of the three heroes imprisoned in the aluminum shell. As soon as they recover from the shock—actually it would have done more to them than just kill them—they begin to spout astronomical and mathematical wisdom in large doses. They get an additional reason for doing so because their projectile passes earth's "second moon" and slightly deflects its course. This proves to be their salvation for, instead of striking the moon, the shell misses and, caught by the force of lunar gravitation, circles around it. Unfortunately for Jules Verne's readers, the circumstances are such that the side of the moon which cannot be seen from earth is in darkness, and all that the three heroes can see is what appears to be a volcanic eruption. Finally they cross into the field of terrestrial attraction and fall back to earth, landing safely although tumultuously in an ocean to be rescued.

Although these two books are not easy to read, Jules Verne's two-volume story of a shot to the moon has become the classic moon-trip story and its fame is universal. This has had the rather unfortunate result of associating space travel with shooting in the minds of most people. But what Jules Verne really accomplished was to acquaint the public with the fact that a trip to the moon is a question of velocity. That he used a gun to produce that velocity is merely a literary device which is not to be taken seriously.

Just the same, this method has been examined critically more than once, and such an examination of Jules Verne's cannon shot

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succeeds in discovering this apergy and sets out for a trip to Mars where he finds people greatly resembling those of earth, only somewhat smaller in stature. The remainder of the story is devoted to a description of Martian society, but the novel is not an utopia. That society is by no means an "ideal state," and there are a lot of things wrong with it. It is a different society, logically constructed.

The date of that novel is, as has been said, 1882. And we are now entering the period of speculations about Mars. After the "moon mountain" of Hansen's hypothesis had collapsed, the moon had finally been given up as dead. Venus was neglected and Mars was to rule supreme.

This shift in interest was not accidental; it was the logical result of scientific developments. The progression of these developments was about as follows: In 1828 Wöhler had shown that living substances consist of the same elements as non-living matter. In 1859 Kirchhoff and Bunsen had developed the spectroscope which, within its natural limitations, proved that the other stars and planets consisted of the same elements as earth, although the distribution of elements varied.

As if to make the case airtight as soon as possible, Dimitri Mendeleeff and Lothar Meyer—working independently—produced the periodic system of the elements, showing that only a limited number of elements were possible at all. Mendeleeff's work was published in 1869. Charles Darwin's *Origin of Species*, published for the first time in 1859, had to be added to these developments in the fields of physics and chemistry. The storm about Darwin did not break immediately, but around 1880 it was already clear who would win. Now Darwin's theory meant that all life was interrelated, not only in a symbolic manner of speaking, but actually. Wherever life started at all it was likely that it, given enough time, would produce intelligent beings in the end. And it seemed probable that life would start wherever conditions were suitable and that it would start soon after conditions became suitable.

On top of all this, astronomers believed they had a correct explanation of the formation of a planetary system of a sun. It was the so-called Kant-Laplace hypothesis—in spite of its name it was mainly Laplace's conception—which stated that the planets had condensed out of matter that had been thrown off their suns. Obviously then, the relative ages of the various planets could be

read off their distances—those farthest away were the oldest.

Mars, therefore, was older than earth by an unknown number of years, probably a large number. Consequently life had started that much earlier on Mars; consequently Martian humanity was older and wiser than we are. By the same token Venus was younger and had probably not progressed to intelligent beings yet; Venus was a replica of the earth at the time of the carboniferous forests or at the time of the great dinosaurs. But Mars was a replica of the earth as it was to be later; looking at Mars one looked, actually and almost literally, into the future.

The year 1877 approached.

It was the year in which Asaph Hall discovered the two small moons of Mars. But it was also the year in which still more exciting news about Mars came from Italy, originating from an astronomer by the name of Giovanni Schiaparelli. The news said that Schiaparelli had seen *canali*.

Now the Italian word *canali* simply means "grooves" or "channels." The meaning of "canals" is secondary, although the word is used to mean artificial waterways too. But in all other languages the word "canal" means only that, and Schiaparelli's *canali* was quickly and emphatically translated into "canals." The jubilation was great; everything seemed to fit perfectly. The planet which had logically been pronounced the most likely abode of intelligent life in our solar system now showed by gigantic works of engineering that it really was.

Mars, as had been suspected from the combination of Kant-Laplace and Darwin, was older than the earth. Because of its age it had lost most of its water. But its inhabitants, also because of their greater age, had progressed in technological knowledge and in the spirit of mutual co-operation to the point where they could overcome that handicap. They had covered their planet with a network of canals which led the water from the melting polar icecaps over all the continents. Those Martian canals were waterways, but they served as means of transportation only secondarily; primarily they served as gigantic irrigation ditches, as center lines of irrigated farm land.

This conception also disposed of the first critical argument—the fact that a Martian canal, to be visible from earth, would have to be at least thirty miles wide and that many of them were three, five, and even ten times that wide. Of course the lines we saw were

that wide or else we could not see them. But what we saw was not the canal itself; it was the wide ribbon of vegetation that stretched through the deserts alongside the canals. There was one river on earth which probably looked to the Martians like one of their canals, for the same reason and especially because it happened to be almost straight: the Nile!

Everybody knows that Schiaparelli's first announcement was followed by three decades of Mars enthusiasm, three decades during which reports from astronomical observatories were awaited and read as avidly as reports from the front in the middle of a war. Several amateur observers reported light signals from the Martians which mostly turned out to be high-flying whitish clouds. Astronomers made careful maps of the surface of Mars, and many who studied them looked for something on the order of the mathematical forest in Siberia proposed by Gauss. Such convictions were so strong that they led to a qualifying paragraph in the famous *Prix Guzman* which was deposited in Paris some time around 1900. The prize amounted to 100,000 francs, then \$20,000, and the award was to fall to the person or persons who established interplanetary communication. But Madame Guzman, when founding the award, stipulated that Mars was excluded from it because communication with Mars would be too easy to deserve a prize.

It goes without saying that literature did not fail to contribute to these decades of the great dreams.

Much later, in 1927, the popular astronomical museum at Treptow near Berlin staged a "Mars Exhibit," consisting of maps of Mars, greatly enlarged photographs, and a large collection of books. And at that exhibit I met an elderly gentleman who swore that he had originally learned German for one reason only: to be able to read the novel *Auf zwei Planeten* by Kurd Lasswitz.

Kurd Lasswitz was a professor of mathematics in his private life, a great deal of which he spent quietly at Jena. *On Two Planets* was neither his only book nor his only work of fiction, but it was the one that made him famous, causing articles in the *Annals of Science* even now, forty years later.

Kurd Lasswitz had carried that logic about the older Martian race a few steps farther. If the Martians were so much older it would be a succession of Martian inventors and scientific institutions which would solve the difficult problem of space travel, and not a single terrestrial inventor. Consequently they would visit the

earth, not the other way round. Also, these *canali* were really strips of vegetation through the deserts, wide bands of tall forests. (Under the lighter gravity of Mars trees would be higher.) Those forests shadowed the buildings of the loosely built cities and the moving roadways. (When traffic is too heavy in volume a moving roadway is superior to independent vehicles.) The precious water was carried in pipes to prevent it from evaporation, and none of the carefully preserved water was wasted on edible plants; food, under the Martians' advanced chemistry, would be synthetic and so inexpensive as to be virtually free.

It was partly a "utopia" portraying a higher society, partly it was simple prediction: engineers have often considered rolling roads for specific traffic problems. And there cannot be a better solution for the basic problem of sociology, eliminating hunger, than synthetic food which can be produced in any volume required at very short notice.⁵ It was also basic psychology to show that the highly ethical Martians, when confronted with terrestrial stubbornness, quickly revert to war, fought in a highly efficient manner with a minimum of actual killing.

But the most interesting thing in Lasswitz' novel was his solution of the problem of space travel. Lasswitz saw to it that his readers got acquainted with it early in the book.

The novel began with a flight to the North Pole in a free balloon; the tragic attempt by Andrée to reach the Pole in this manner was still fresh in everybody's memory. When the Pole comes into sight, the men in the gondola see to their great surprise that there is an unmistakable building on the Pole, strange in shape, but not an Eskimo hut. At the same time the balloon begins to circle as if caught in a whirlpool, but it also begins to rise. Minutes later the balloon rises vertically, and the gondola rises faster than the gas-bag. They are caught in a field of reversed gravity, induced by the connection between the building on the Pole and a structure high above the Pole, one earth-diameter from the center of the earth.

These are structures of the Martians, their first foothold on earth.

⁵ Later, when synthetic food is introduced on earth, it becomes more than just a chemical problem. Lasswitz compresses the whole struggle in one scene, the scene where a man who has been out of touch with events, orders supper in a small restaurant, deciding on a liverwurst sandwich. The waiter asks whether he wants natural or synthetic.—"What, synthetic?"—"Yes, sir, Martian style, sir. You see, sir, 'grown' is considered patriotic, but synthetic is much less expensive and, really, it's much better."

The Martians get the travelers out of the field by turning it off as soon as the car which happened to be in transit between the Pole and the "outside station" has arrived on the latter. Revived, the three earthmen are informed about the accident that has happened to them. Later on they are taken to the outside station and asked to point out their homes, the Martians do have that kind of telescope that Locke ascribed to Sir John Herschel. But Lasswitz explains it better. The original image falls on a small screen consisting of millions of tiny photo-electric cells. Each cell operates an "optical relay," releasing visible radiation of precisely the same color but of much higher intensity, and these rays form the image on the large screen. (Lasswitz, incidentally, had astronomical experts check the precise range of such a presumed instrument in that presumed position.)

And then the earthmen learn how the Martians crossed space. They succeeded in developing a material which, although not weightless in itself, had the quality of becoming so as soon as it formed an unbroken shell. Lasswitz vaguely indicates that gravity will "flow around it" in this case. And all the things inside become "inaccessible" to gravity. Thus a Martian spaceship—they are spherical—becomes weightless as soon as the last door is closed. If that were done near earth the weightless ship would at once move away from earth's orbit along a tangent and in time reach the orbit of Mars, to land on Mars if the planet happens to be near that point of its orbit at that time. Or else the Martians can take off from the home planet in the same manner, wait until their planet is sufficiently far away, fall toward the sun until they have reached the orbit of earth, and then land on earth.

The first attempts, the earthmen are told, were unsuccessful and ended in disaster, partly because of the clumsiness of the method, partly because that marvellous substance, developed on Mars, disintegrated in the moist atmosphere of earth. They had to have two improvements. One was the station over the Pole—they have similar stations over their own poles because "you do not jump onto a train where it moves but where it stands still"—and secondly a method of steering, accelerating, and stopping their ships in space. The solution to the latter problem was *repulsit*, a substance somewhat beyond the grasp of terrestrial physicists, but essentially a highly explosive substance. The reaction of such an explosion

would steer or stop or accelerate their ships, but they always needed quite a number of such "shots," each releasing a small dose of *repulsit*, since the jolt resulting from a dose of the proper magnitude would have killed every man aboard. Still, they could and did travel that way, finding only the earth inhabited by a race similar to them. But just recently a Martian engineer by the name of Fru has made the final invention they need, Fru's *repulsor* which releases the *repulsit* charge in a prolonged push instead of a sudden explosion.

Disregarding the marvellous but impossible (and what's more, actually useless, as we'll see later) substance which makes things inaccessible to gravity, Lasswitz presented a solution of the problem of space travel as mathematicians see it. Once free of the immediate gravitational influence of a planet, a spaceship would drift to the orbit of another planet in a time interval which can be calculated, and it is a question of timing the departure whether you meet the other planet at that point of its orbit or not. The reaction of a shot—preferably a pushing instead of jolting reaction—can be used as means to decelerate or accelerate in airless space. It was all worked out so well that most readers, as one critic put it, did not even notice that these pages of the book (only a score or so) presented a number of new thoughts.

One of the results of Lasswitz' novel was the reissue of Kepler's *Somnium*, and the *Somnium* greatly influenced H. G. Wells when he wrote his *First Men in the Moon* a year or two later. In this novel, as most readers will remember, Wells uses a substance very similar to Lasswitz' Martian invention, but ascribes it to an earthman, the engineer Cavor, and consequently refers to it as *cavorite*. Cavorite gets them to the moon and the two space-travelers are finally captured by the selenites who live in the numerous hollows and caves under the volcanoes.⁶ The selenites are evolved from insects and Wells infuses these beings with the specialized nature of members of a termite colony. Finally one of the travelers escapes and returns to earth.

Wells' other early interplanetary novel appeared almost simultaneously, the *War of the Worlds*, and describes an invasion of the earth by the Martians. In this novel Wells used Jules Verne's

⁶ Wells probably misread *subvolcani* as *subvolcani*, converting the "dwellers under the Volva" into "dwellers under the volcanoes."

method of shooting, but the book itself is devoted to the description of the attempted Martian conquest. The Martians are described as octopus-like creatures, rather frail, at least under the pull of terrestrial gravity. Consequently they move about mechanically, sitting in towering fighting machines equipped with heat rays and poison gas nozzles. Finally the Martians succumb, not to human opponents but to the "invisible devils" of which the terrestrial atmosphere is full. They die of bacterial infections—a pretty idea which has been imitated countless times since.

The two Wells novels were the last two important works of literature of this type produced by the decades of the great dreams of human life on Mars. Many more novels of this kind have been written and published during the last forty years, of course, but in most cases the authors have described the conquest of space as originating from earth. The Martians, by their very failure of visiting our planet, have proved that their intelligence has to be at a lower level than ours if they exist at all. Even that is now generally doubted and with many good reasons.

And with Mars out of the running, earth remains the only planet in our solar system which bears intelligent life. Little Mercury, the moon of the sun, has one hemisphere freezing in endless night while the other is scorched by endless day, an endless day in close proximity to a viciously radiating sun. Venus, sister planet of the earth as far as size and mass goes, is somewhat too warm—the estimates of its surface temperature range from 80 degrees Fahrenheit to the boiling point of water.

The moon is dead and without atmosphere. The atmosphere of Mars is thin, but dense enough to support the rare clouds. At noon in summer the Martian equator acquires a temperature which is comparable to a balmy spring day on earth in the temperate zone, but generally speaking the climate of Mars rather resembles the arctic zone of earth, or the icy cold of the high ranges of Inner Asia.

Still it is quite likely that there is plant and even animal life of some sort on Mars; the conditions are not such that life would be impossible. And the same can be said about Venus, provided that the surface temperature is sufficiently below the boiling point, something we are, at present, unable to determine.

As for the large outer planets, the present conception is that they are wrapped in miles upon countless miles of highly compressed ice under an enormously deep and dense atmosphere of extremely

cold hydrogen gas, topped by layers of clouds of marsh gas and ammonia.

Being confronted with scientific evidence of this kind, newer novelists have had no other choice than to let the conquest of space originate from earth. The chances are overwhelming that future developments will prove them correct.

Chapter 3:

"THE ROCKETS' RED GLARE . . ."

Actioni contrariam semper et aequalem esse reactionem; sive corporum duorum actiones in se mutuo semper esse aequales et in partes contrarias dirigi.

Reaction is equal (in power) but opposite (in direction) to action; or the actions of two bodies are equal (in power) but point in opposite directions.—Sir Isaac Newton's Third Law of Motion.

THE story of the rocket is part and parcel of the story of flight as well as of space travel. While this connection may have been accidental in a number of early instances, it is anything but accidental today. The application of rocket power to theoretical devices for reaching outer space is solidly founded in scientific fact, as will become apparent later on.

If it were only a question of theory, the old powder rockets of several centuries ago could safely be neglected in a modern discussion. But the application of rocket power is also a problem of engineering design, and it is for this reason that the history of the rocket is important, mirroring, as it does, a long period of small achievements by the trial and error method and showing the limitations of the devices developed by the traditions of families of artisans.

With this remark I refer, of course, to the later European tradition of which we have knowledge. But the rocket is not a European invention; the Europeans got it from the Arabs and the Arabs, in turn, had it from the Chinese.

There has never been any doubt that the rocket, the ordinary skyrocket, is originally a Chinese invention. But for want of definite knowledge, its origin has often been shrouded in legend and its age has been vastly exaggerated.

Older books often state in an offhand manner that rockets and similar fireworks have been known to the Chinese since the earliest times, probably since 3000 B.C. Where the authors of these books got their information is something a historian with a talent for languages should investigate some day. There is no reason, and there

never was a reason, to believe in such a high age. The oldest known Chinese source in which rockets are mentioned is a chronicle known to sinologists as the *T-hung-lian-kang-mu*, and that chronicle dates the first use of the invention—though not the invention itself—as having been made in A.D. 1232. The occasion was a siege laid to the city of Kai-fung-fu (Pien-king) by the Mongols. But the Chinese had two new weapons and the Mongols disliked them intensely. One of those weapons was a kind of bomb dropped from the walls of the city on the heads of the besiegers. The Chinese name for that weapon is *tchin-tien-lui* or "heaven-shaking thunder." The other new weapon goes under the name of *fe-ee-ho-tsiang* or "arrow of flying fire." These "arrows" are taken to have been rockets and the description supports that supposition.

That description, according to the French sinologist St. Julien, reads as follows:

The defenders also had "arrows of flying fire." They attached an inflammable substance to the arrow. The arrow suddenly flew away in a straight line and spread its fire over an area measuring ten steps. The Mongols dreaded these arrows of fire very much.¹

Those "arrows" are taken to be rockets because no mention is made of a bow or any other instrument for shooting them. It is merely stated that they flew away suddenly and in a straight line. It is quite possible that they were real arrows with a rocket tied to them. Drawings of such rocket-arrow combinations have been found in ancient Chinese manuscripts by the French Jesuit Father Amiot. And travelers who have paid attention to such minor matters have asserted that Chinese fireworks rockets, at least as late as the year 1900, were feathered at the lower end of their guiding sticks, just as if they were arrows and notwithstanding the fact that the feathers burned away very quickly when the rocket was ignited. The arrows of Pien-king were literally "arrows of flying fire," a term which, to a European, would mean something entirely different: a fire arrow.

Fire arrows or incendiary arrows consisted of a small package

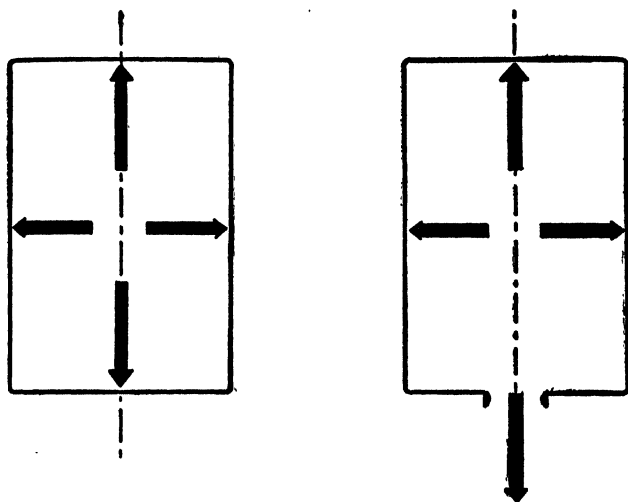
¹ In *Journal Asiatique* (1849). The original reads: "De plus, les assiégés avaient à leur disposition des 'flèches à feu volant.' On attachait à la flèche une matière susceptible de prendre feu; la flèche partit subitement en ligne droite, et répandait l'incendie sur une largeur de dix pas. Les flèches à feu volant étaient très redoutées des Mongols."

of incendiary materials tied to an arrow. Such arrows were dangerous weapons in times when most fortifications consisted of wood, and they were even more dangerous in later naval battles when sailing vessels had extensive tarred riggings. But rockets often substituted for fire arrows in these later naval battles and it seems that the two, the fire arrow and the fireworks rocket, are actually related to each other—in fact the one is the ancestor of the other.

The story of the fireworks rocket prior to the siege of Kai-fung-fu is not known, but more than half a century ago S. von Romocki evolved a brilliant conjecture about this unknown part of the rocket's history, a conjecture which has never been contradicted and which seems to be as close to actual truth as may be hoped for under the circumstances.

The fire arrow, the real fire arrow that was shot from a bow, was always an effective weapon in the wars of those days and it is only logical that many men sought to improve upon it. The main drawback of the fire arrow was its short range; it could not be shot from a fully drawn bow because that would extinguish the flame of the small package of incendiary materials tied to the shaft. Obviously it was necessary to find a material that would not be extinguished that easily. Now Greek philosophers held that salt, when added to an incendiary mixture, would make the flame hotter. The simple truth of the matter is that it merely makes the flame brighter, but since there was no way of measuring flame temperatures—or temperatures of any kind—in those days, the idea that the brighter flame was also the hotter flame was as obvious as it was beyond proof or disproof.

This "secret," the addition of salt to incendiary mixtures, seems to have traveled to China. And the Chinese seem to have substituted saltpeter for salt, either because they were not satisfied with the results of the "secret" or else because they accidentally discovered the properties of saltpeter. But when they added saltpeter they had a real improvement because then their incendiary mixture was well on the way to becoming gunpowder. Gunpowder, as every schoolboy knows nowadays, consists of a mixture of saltpeter (about three parts) and of pulverized charcoal and sulphur (constituting the fourth part in about even proportions). By about A.D. 1200 that process seems to have been completed. Hence the defenders of Kai-fung-fu had bombs which exploded with noise and violence and they also had fire arrows which had grown power-



3. *Elementary Principle of Rocket Motion.*

ful enough to depart of their own volition when ignited, without requiring a shooting instrument.

After the siege of Kai-fung-fu there is a little gap in the story of the rocket and, since it is necessary to understand the motive power of a rocket before we go on, that gap may be utilized for the necessary explanation.

A rocket is essentially a vessel filled with gas under pressure, gas meaning anything that is gaseous—compressed air, if you will, or steam under pressure, or carbon dioxide—any gas will do. As long as the vessel containing the compressed gas is without leaks or holes, nothing will happen; the gas will press against the walls of the container with equal force in any direction, up and down and left and right. But the picture changes when the container gets a hole through which the gas can escape. We'll assume that the hole appears suddenly in the bottom of the container. Then the gas still presses against the walls and the top, but it cannot press against the bottom because there is nothing to press against. Consequently the pressure pointing upward is not counteracted and the container rises. (Fig. 3.)

Abandoning historical sequence we find a perfect illustration of this principle in the steam rockets for which Mr. James Perkins

of London was granted a British patent on May 15, 1824. Mr. Perkins' rocket consisted of a metal container which was partly filled with water. A round hole in the bottom was closed with a plug of a metal alloy which melted easily, probably a lead-tin alloy. Then the whole thing was placed into a blazing bonfire. The heat soon changed the water into steam which tried to get out of the confined space. But the container held together until the whole rocket had become hot enough for the plug to melt. Then the steam could push it out and suddenly, with a hole through which the steam could escape, the rocket shot up into the sky. I don't know whether Mr. Perkins knew precisely just what he was doing, nor do I know for what purpose he constructed these steam rockets and why he went to the trouble and expense of acquiring a patent, but I feel grateful for his efforts because he provided such a simple demonstration of the basic principle of rocket motion.

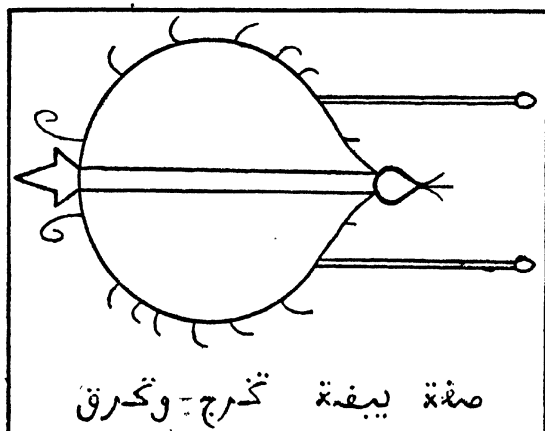
But to go back to the powder rocket.

Its principle is the same with only a minor difference of mechanics involved. Instead of being charged with a compressed gas, the powder rocket is charged with a mixture which, when burning, produces large quantities of compressed gas. Real gunpowder, incidentally, burns too fast for this purpose; it has to be slowed down—"made lazy" as the pyrotechnic term has it—by adding a large amount of pulverized charcoal. But those early gunpowders were all "lazy"; the weak mixture accidentally proved to be the right mixture.

The Chinese invention of the powder rocket, made some time around A.D. 1200, traveled back to the West with amazing speed. Just eight years after the battle of Kai-fung-fu an Arab scientist, usually referred to as Ibn Albaitar ("Son of the Horse Doctor"), wrote a book in which the important ingredient of gunpowder is mentioned.² Saltpeter, "the flower of the stone of Assos," as he has it, "is now called 'Snow from China' by the Egyptians," he stated, pointing to the influence of the Chinese discovery. As for the "people of the West" (the Arabs), he continued, the substance is called *barood*—but at that point he stopped; he did not say what they, or the Egyptians for that matter, did with *barood*.

We get more complete information about the things Ibn Albaitar may have been hiding from another Arab manuscript,

² His full name was Abu Mohammad Abdallah Ben Ahmad Almaliki (from Malaga).



4. The Self-Moving and Combusting Egg.

the *Book of Fighting on Horseback and with War Engines*. It was written by one Hassan Alrammah, described as a brilliant hunchback whom his contemporaries adoringly called *Nedshin Eddin*, "Star of Faith," and who seems to have completed his manuscript in A.D. 1280. The book contains recipes for making gunpowder and directions for making rockets. And the rockets are still called *alsichem alkhatai*, Chinese Arrows.

But Hassan adds one unsuspected novelty: a rocket-propelled torpedo consisting of two flat pans, fastened together and filled with powder or an incendiary mixture, equipped with a kind of tail to insure movement in a straight line, and propelled by two large rockets. The whole was called the "self-moving and combusting egg," but no instances of its use are related. (Fig. 4.)

Some thirty years before Hassan finished his book, rockets and powder (which was not yet gunpowder because the guns were still to be invented) had been introduced in Europe. The rockets go under the Latin name of *ignis volans* (flying fire) or under the Germanic name of "wildfire," the latter being used later also for the old Greek fire which was a pure incendiary without explosive qualities.³

³ I have told the story of gunpowder and rockets in Medieval Europe with more detail in my book *Shells and Shooting* (New York: Viking, 1942); see the chapters "Masters of the 'Black Art,'" "The Ancestors of Artillery," and "Rockets in Battle."

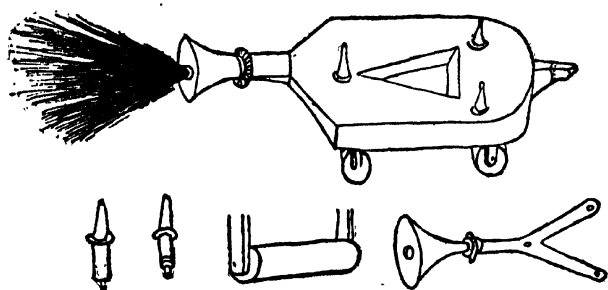
Shortly before 1249 the *Doctor mirabilis*, Roger Bacon, wrote his *Epistola*; some time between that date and 1280 (the year of his death) Roger Bacon's German counterpart, Albertus Magnus, wrote his *De Mirabilibus Mundi*, and the book of one Marchus Graecus, the *Liber ignium*, became known. All these books mention powder and rockets, and they all do so in the same words, proving a close interrelationship of the various books. Without going in for the rather difficult historical evaluation of the various manuscripts and works, it may be stated that the *Liber ignium* has been found to be the source for all the others. And the *Liber ignium* itself, of which only two apparently shortened and incomplete manuscripts were preserved in Paris, is probably a translation of a lost Arabic original.

That the introduction of rockets was not just a purely literary phenomenon is proved by occasional references to the thing itself. The chronicle of Cologne speaks about them in 1258 and the Italian historian Muratori credits a rocket with an important victory in the battle for the Isle of Chiozza in 1379. One defending tower resisted all assaults until it was set afire by a lucky hit.⁴

At that time firearms were already in existence, having been invented—according to the only source which gives a date—in 1313, but they were still crude and of poor performance so that rockets were a serious competitor. Naturally the military engineers of that period experimented with both, guns as well as rockets, trying to improve their power and range. Consequently there existed more than one type of rocket in 1400. The German military engineer, Konrad Kyeser von Eichstädt, mentions three types in his book *Bellifortis* (finished in 1405): vertically rising skyrockets, floating rockets, and rockets running along taut strings. The sketchbook of an Italian military engineer, Joanes de Fontana, which can be dated as having been finished in 1420, is full of much more ambitious projects.

This sketchbook, later called the *Bellicorum Instrumentorum Liber*, contains drawings of rockets disguised as flying pigeons, as floating fish, and as running hares, all of them supposed to set fire to the enemy's fortifications. The running hare, mounted on a wooden board, does not run on wheels but on wooden rollers—de Fontana was looking for a device that would enable his disguised rocket to cross uneven ground. The same idea, magnified

⁴ The original reads: "Pure una rochetta fu tirata nel tetto della torre de si fatto modo, que il tetto s'accese."

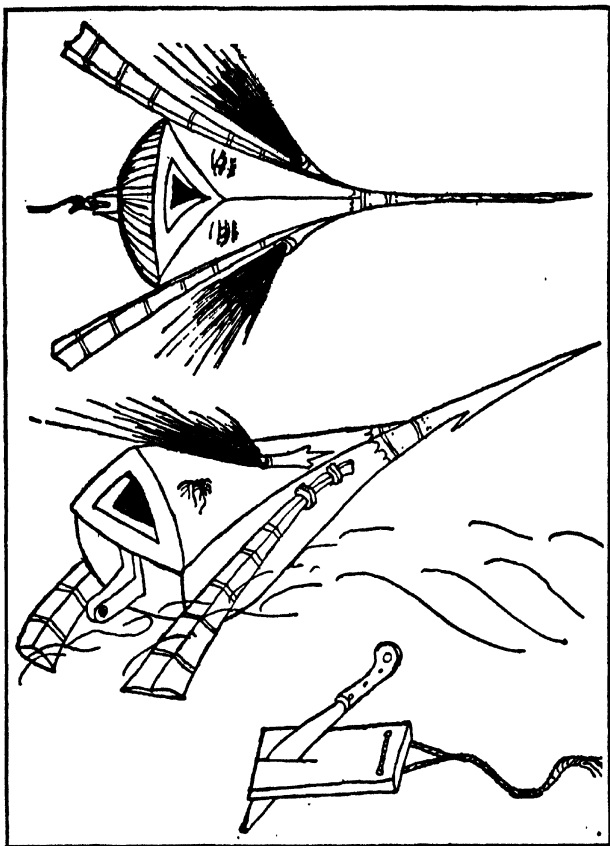


5. Fontana's Rocket Car.

in size, resulted in the sketch of the first rocket car, apparently expected to breach walls or at least gates. And finally de Fontana also sketched a wooden rocket torpedo, painted so as to resemble the head of a large sea monster. (Figs. 5 and 6.)

Most of these sketches were probably nothing but ideas which were never tried, but books on military matters which were published during the two centuries following de Fontana contain a number of ideas which look as if they resulted from actual experimentation. Rockets with crude parachutes are described in a heavy manuscript—it never saw print—compiled by Count Reinhart von Solms during the first part of the sixteenth century. A little later the Count of Nassau described a rocket which would dive and finally explode under water. Like that of the Count von Solms, the manuscript of the Count of Nassau was never printed. It is an enormous folio tome of 725 pages, completed in 1610.

But by then rockets were not weapons any more, except at sea where the riggings of sailing vessels offered large and highly inflammable targets. The book by Leonhart Fronsperger (important for its history of artillery), which was published in Frankfort-on-the-Main in 1557, speaks of rockets in connection with a description of fireworks for amusement. Only thirty-four years later one Johann Schmidlap published the first book to deal exclusively with non-military fireworks (Nuremberg, 1591). It is a thin folio volume and it begins with an interesting introduction in which the author states that the publication of his book may irk other fireworks experts. It seems that a number of trade secrets were published there for the first time. The manufacture of fireworks rockets had become a definite practice by then, a standard practice which must



6. Fontana's Rocket Torpedo.

The dagger thrust through the tail piece indicates that the building material is wood.

be described because it has remained standard up to this day, with only minor modifications.

The raw material for the making of a rocket was "lazy" gunpowder and pasteboard, together with a few simple tools, mostly made of hardwood. The first step was the pasting of the tube which was shaped around a cylinder of hardwood that was rounded off at one end. Then, while the paste was still moist, the tube was

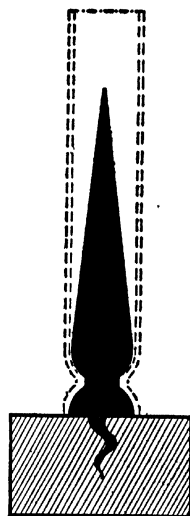
7. Mechanism for Making Powder Rockets.
The rocket tube (dotted outline) is pushed over the
“thorn” (solid black) and the powder charge is
hammered in around it.

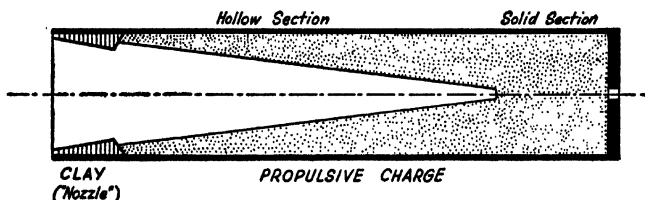
“throttled” by pulling the wooden cylinder out for a little more than the diameter of the tube so that the rounded-off end was at this point inside the tube. Another rounded-off plug was inserted and then a soaped string was looped around the moist tube at the point where the two rounded-off cylinders of wood met inside. By pulling the soaped string back and forth the tube was constricted to about two-thirds its full diameter. After that it was permitted to dry thoroughly.

When dry, the tube was filled with powder which was hammered in solidly, layer after layer, until the tube was filled to the top. The end which had been constricted formed the lower end of the rocket and the fuse was put in through the constriction or nozzle. The important point was that the powder was hammered around a “thorn” (see Fig. 7) so that the powder charge had a center hole, usually conical in shape, which reached almost all the way through. The purpose of this center hole—Konrad Kyesser was the first to mention it—was to provide a large burning surface for the powder so that a large amount of gases would be generated. For some reason this center hole was called the “soul” of the rocket, which set mystically inclined characters to speculating about the “power of the rocket soul.”

This standard practice, which may even be an Arab invention, has survived until now—most fireworks rockets are still made in this manner. Only the larger factories have adopted some modifications, for example, hydraulic pressure in lieu of hammering. Such a “pressed rocket” is usually made solid, with a layer of clay at one end. The “soul” is then bored out through the layer of clay, the remains of which serve as a primitive nozzle, obviating the need for the tedious “throttling” of the tube.

The finished rocket, according to Schmidlap’s description, is then tied to a straight stick “which must be about seven times as





8. Ordinary Powder Rocket.

long as the rocket itself. You then balance your rocket on your finger or on the back of a knife blade, placed just below the firing hole. If it balances well the stick is just right; if the stick be heavier, cut it until the rocket balances, but cut from its thickness only so that it have its full length."

This test, also, is still in use for handmade rockets.

But all the time, from the Chinese and Arabs on, none of the countless artisans who fashioned rockets had the slightest idea of what he was doing. Burning gunpowder produced a blast, that much was known. And an Italian, Vannoccio Biringuccio, had explained in fair detail just what happened. This is what he said:

One part of fire takes up as much space as ten parts of air, and one part of air takes up the space of ten parts of water and one part of water as much as ten parts of earth. Now powder is earth, consisting of the four elementary principles, and when the sulphur conducts the fire into the driest part of the powder, fire and air increase . . . the other elements also gird themselves for battle with each other and the rage of battle is changed by their heat and moisture into a strong wind. . . .⁵

Biringuccio had observed the phenomenon correctly enough; it was not his fault that he had no better technical language at his disposal than Aristotelian nonsense.

The artisans who fashioned powder rockets knew, from Biringuccio's explanation as well as from direct observation, that something for which they had no better term than "a strong wind" emerged from the nozzle of a rocket. They lacked knowledge of the reason why this strong wind, which evidently was blowing downward, should carry the rocket upward. Another century and a half passed before Newton found out why this happened. But

⁵ In *De la Pirotechnia*, published first in 1540. An English translation was published in 1943, while a German edition appeared some twenty years ago.

Newton's explanation, couched in a crisp Latin sentence, could not be understood well at first. There are still many people who don't understand it and help themselves with the essentially lazy explanation that the blast of the rocket pushes against the air.

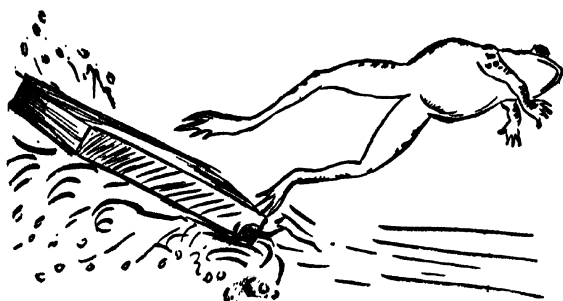
An explanation why "every action is accompanied by an equal but opposite reaction" is now required. That explanation has been given many a time, clothed in similes involving exploding sticks, wooden balls that are pushed apart by expanding springs, and all kinds of other things that nobody has ever seen unless he has made them for the experiment.

Perhaps the simplest explanation of the Third Law of Motion is made by means of a frog and a piece of wood, floating on a quiet lake. The frog weighs one ounce and so does the piece of wood and nothing happens for some time. Then the frog sees a fly a short distance away and he jumps violently off the piece of wood. The frog, of course, gets to the fly and the piece of wood gets elsewhere—in the opposite direction. Assuming that the resistance of the water did not exist in this case, the wood gets as far as the frog. If the frog, in pushing himself off the piece of wood, acquired enough speed to sail through the air a distance of four feet, the wood also got a sufficiently strong push to move four feet in the opposite direction, both (because of their equal weight) moving with equal speed. (Fig. 9.)

When everything is over we will have the picture of a 1-ounce frog 4 feet from the original resting place due north, and a 1-ounce piece of wood 4 feet from the original position due south. If both had moved along the balance of a scale, the scale would not even have quivered because of the perfect distribution of the two weights to the right and to the left of the original center. This is the important point—the two components will balance each other perfectly at any given moment.

In the case of a rocket, the rocket itself is the piece of wood of our example and the powder gases are the frog. The gases, in "jumping" away from the rocket, "kick" it back—something that would happen in airless space as well as in air and that has nothing at all to do with "pushing" against the air.

It is precisely the same force which kicks a gun barrel backward when the projectile and a stream of violently expanding explosive gases emerge from the muzzle. It is the same force which makes a chair topple over when a cat jumps from its back onto the book-

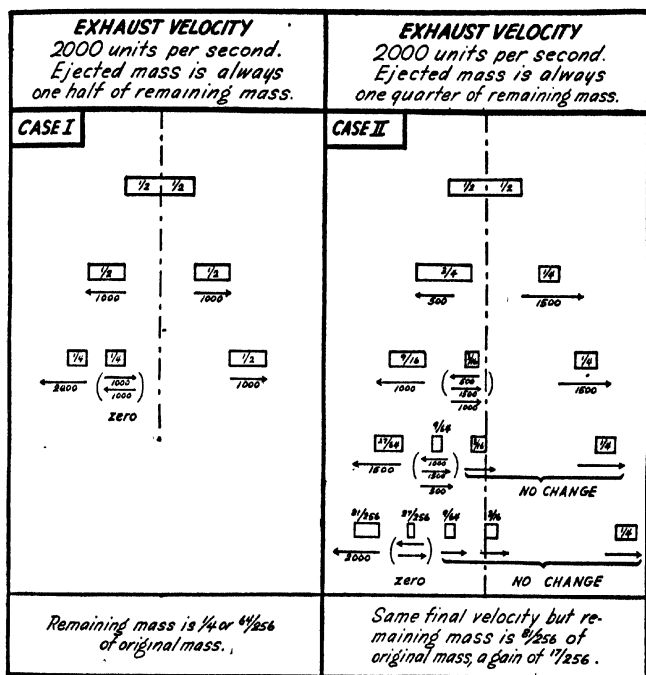


9. *The Third Law of Motion.*

shelf, the same force which kicks your canoe back into the river when you jump ashore.

The reason why it sounds so strange to the average man is that it is not noticed much in everyday life. Not because it is not there, but because it is not wanted. Ordinarily the action is the wanted part of the whole procedure; the reaction is a nuisance and therefore overlooked. But it can be utilized. You can, for example, propel a light canoe by throwing heavy stones with all your might over the stern. It is not very efficient and it is exhausting too, but it shows that you don't "push against the air."

The real rocket does not throw stones. It ejects gas molecules instead. The effect is, naturally, the same, but there is a certain advantage connected with the ejection of very tiny particles. In the case of our frog, both parts of the whole system were halves.



10. The remaining mass of a rocket-like mechanism increases as the size of the particles ejected decreases.

The result was that half of the total mass attained half the total jumping speed. If there had been several smaller frogs on that piece of wood, the final result would have been better.

Fig. 10 shows what happens to the original mass if you eject halves—"halves" (and later "quarters") always means halves, or quarters, of the mass that is still available after one ejection has taken place. If you eject halves you attain total exhaust velocity, as the mechanical equivalent of the jumping speed is called, and you have, in the end, one quarter of the original mass left. If you eject quarters, you attain full exhaust velocity with $81/256$ of your original mass left. Since one quarter is $64/256$, you have "saved" $17/256$ or roughly $1/15$ of the original mass.

It is obvious that the amount "saved" increases as the size of the ejected particles decreases. The limit is reached when the particles

become infinitesimally small. With such small particles you can attain full exhaust velocity if your original mass is 2.72 times as large as your remaining mass, whereas in the case of ejecting halves it had to be four times as large as your remaining mass.

We now come to a very important point. There is, of course, no reason why the ejection of particles should not be carried on even after the rocket has reached full exhaust speed. Naturally it is possible to go on, provided only that there is still some ammunition left. And that means that a well-built rocket *can attain a velocity which is higher than the exhaust velocity*.

The foregoing discussion—which is repeated in the form of tables and formulae in the *Addenda*—has brought out several important facts that may be summarized as follows:

(1) The motion of a rocket is essentially independent of the surrounding medium—a rocket can move under water as well as in air or in a vacuum. The surrounding medium appears only in the form of resistance against both, the motion of the exhaust as well as the motion of the rocket. The attainable velocities and efficiencies will, therefore, be higher the thinner the medium in which the motion takes place.

(2) The exhaust of the rocket should consist of very small particles, which is normally an accomplished fact since the exhaust usually consists of a gas.

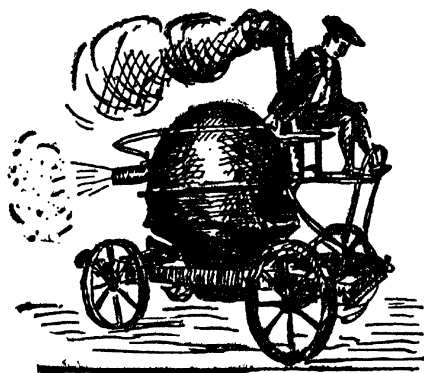
(3) The velocity of a rocket might be increased either by increasing the mass of the exhaust or by increasing its velocity. If a choice is possible, the latter method is superior.

(4) The velocity of a rocket can exceed the velocity of its own exhaust. The velocity of the rocket is limited only by the amount of mass (fuel) which can be ejected.

All this is contained in the simple statement which has become known as Newton's Third Law of Motion. Other physicists began to understand these possibilities after Newton had pointed the way. While most of it was, at first, of purely academic interest, one fact of possible practical usefulness was realized quickly: rocket motion did not depend on some mysterious quality of gunpowder; it was solely a question of ejecting a mass of some sort at high speed.

It seemed possible to propel a vehicle that way—a thought which was highly intriguing at a time when no motor of any kind existed.

Experimenters began to wonder about direct reaction for vehi-



11. Steam Reaction Car.

cles and a Dutch professor succeeded to a certain extent. His name was Jacob Willem s'Gravesande and one of his works gives explanations and illustrations of Newton's natural laws. The book had the title *Physica elementa mathematica* and it appeared in two volumes, the second in 1721 at Leyden. In this second volume Professor s'Gravesande pictured and described a model car which moved under its own power. The miracle was accomplished by mounting a small spherical metal container on the car with a little fire underneath. The steam produced in the small boiler escaped through a long tube pointing rearward and the model moved.

There are rumors that Professor s'Gravesande later tried to build such a steam reaction car on a large scale, and there even exist some drawings of this vehicle. But since the drawings look as if they were made later and since no direct report of the attempted construction has been preserved, it is uncertain whether s'Gravesande ever really tried, although he may have toyed with the idea. (Fig. 11.)

The description of the small working models was to give rise to a large number of different plans later on—Mr. Perkins' steam rockets of 1824 were only one of them—but at first there was a military interlude. The war rocket was revived with great initial success and for quite some time the words "rocket" and "war rocket" became synonymous. It was what is now called the "Congreve period," after Sir William Congreve, the creator of the British war rockets.

However, the direct cause for that revival did not lie in Europe; it was an unsuccessful military campaign in India, related in a book with the title: *A Narrative of the Military Operations on the Coromandel Coast against the combined Forces of the French, Dutch and Hyder Ally Cawn from the Year 1780 to the Peace in 1784*, by one Innes Munroe, Esq. It was published in London in 1789 and it confirmed other stories that had reached England somewhat earlier. The stories said that the Indian troops employed large rockets to fight the British, rockets similar to those used in England for amusement, but much larger. They consisted of an iron tube instead of the customary pasteboard, their weight ranged from 6 to 12 pounds, and they were guided by a 10-foot bamboo pole. Their range was estimated to be a mile and a half and they were not very accurate, but they did much damage through mass application, especially among the British cavalry.

The Hydar Ali—this is the proper spelling—mentioned in the title of the book, was then Prince of Mysore and the father of the idea of attaching a rocket corps to his regular army. It numbered 1200 men and since the “new” weapon had proved to be so successful, Hydar Ali’s son, Tippoo Sahib, increased the strength of the rocket corps to 5000 men. The British suffered badly from these rockets, especially at Seringapatam in 1792 and 1799.

The news aroused the curiosity of the military in Europe. It looked as if a promising possibility had been overlooked, and the barely noticed experiments of a Frenchman, Citizen Chevalier, suddenly began to look important too. That Frenchman had fired incendiary rockets of a large size against a large target fashioned from an old sail which he intended to set afire. It had not worked simply because the rockets had torn through the old sail so fast that the target had no time to catch fire.

But perhaps there was something to Chevalier’s idea after all.

Several military men and scientists began to experiment in a modest way but only one of them was really successful, the British Colonel William Congreve, M.A. (the “Sir” was not added until several years later). Contrary to a statement that can be found in many books, Congreve had never seen the Indian war rockets in action for the simple reason that he never went to India. His only information came from books and journals, available to anybody interested in the matter.

In 1801 or 1802 Congreve bought the biggest skyrockets available

in London, paying for them out of his own pocket, and began to indulge in some private long-range practice, or rather in firing practice which had the purpose of establishing the possible range. He found it to be between 500 and 600 yards, less than half the range of the Indian war rockets. Then he took the idea to the authorities, apparently aided by his father, Lieutenant General Sir William Congreve, comptroller of the Royal Laboratory at Woolwich. Lord Chatham granted permission to use the laboratories and the firing ranges, and Congreve soon obtained a range of 2000 yards. In 1805 the new weapon was demonstrated to the Prince Regent, and later in the same year Congreve accompanied Sir Sidney Smith in a naval attack against Boulogne.

What happened during that first expedition is not quite clear; some military historians say that the weather prevented the use of the rockets, others state that about two hundred rockets were fired which damaged only three houses and that the French soldiers marched around in the city after the attack, carrying the empty shells of the rockets and making unprintable jokes about them. It is unimportant whether the one or the other claim is correct, because the rockets proved their effectiveness in the years to come. Boulogne underwent a terribly devastating fire raid in 1806, and in 1807 the greater part of the city of Copenhagen burned to the ground, set aflame by a mass expenditure of about twenty-five thousand rockets.

Danzig, in 1813, was very much a repetition of the Boulogne bombardment. The first barrage, fired on August 26, failed to do any harm and the empty burned-out rockets were carried around in the streets and bought by people who exhibited them in stores for a small fee. The second bombardment in September set twenty-three buildings afire, among them the hospital of the Dominican monks. And the third bombardment on October 20 fired the food stores so that the city had to surrender on November 27.

During the days immediately preceding the effective October bombardment of Danzig, the British "Rocket Corps" distinguished itself during the Battle of Leipzig (October 16-19, 1813) which broke Napoleon's power. The Corps had no part in the actual taking of the city, but it had served effectively during the preliminary actions and was granted permission to display the word Leipzig on its standards.

Congreve had started out with incendiary rockets of about 30

ROCKETS

pounds which carried a "carcass" filled with incendiary mixtures. But he steadily increased the size and weight, the stability and also the variety of his rockets, and in 1817 he published the following list of the various types:

WEIGHT AND DESIGNATION	TYPE OF PROJECTILE CARRIED	EXTREME RANGE IN YARDS	ELEVATION FOR EXTREME RANGE —ABOVE
42-lb. Carcass Rocket	Large: 18-lb. Carcass	3000	60°
	Small: 12-lb. Carcass		
42-lb. Shell Rocket	Large: 12-lb. Spherical bomb		
	Small: 5.5-lb. Spherical bomb		
32-lb. Carcass Rocket	Large: 18-lb. Carcass	2000	60°
	Medium: 12-lb. Carcass	2500	55-60°
	Small: 8-lb. Carcass	3000	55°
32-lb. Shell Rocket	9-lb. Spherical bomb	3000	50°
32-lb. Case Shot Rocket	Large: 200 Carbine balls	2500	55°
	Small: 100 Carbine balls	3000	50°
32-lb. Explosive Rocket	5-12 lbs. of powder	2500-3000	55°
12-lb. Case Shot Rocket	Large: 72 Carbine balls	2000	45°
	Small: 48 Carbine balls	2500	45°

Flare Rockets equipped with parachutes.

These rockets represented all types of artillery ammunition then in use, save for the solid round shot. It was Congreve's firm belief that his rockets would replace artillery, except for naval warfare, within a few decades. His favorite term in speaking about his rockets was "the soul of artillery without the body" and in a sense he was right. His rockets surpassed all the easily movable artillery pieces of his time in range. They were about even as far as accuracy was concerned which, from our point of view, was nothing to boast about. His rockets were cheaper; he calculated a saving of 8 pence per round when comparing the 10-inch mortar with a rocket of equal effectiveness, neglecting the cost for the mortar itself. But the main advantage was lighter weight; Congreve's rockets did not need strong and heavy barrels to give them direction. He used thin-walled launching tubes made of copper. And for mass bombardments he needed only collapsible wooden frames which looked like very wide stepladders.

What Congreve did not know—and what he could hardly be expected to know—was that the artillery pieces of his time were

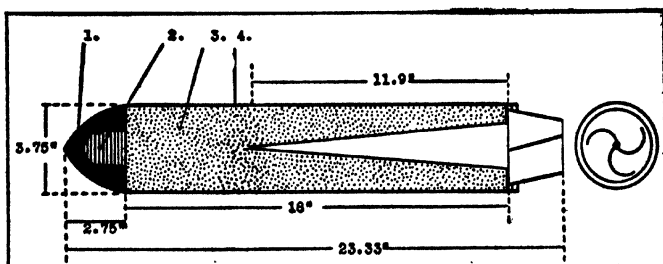
crude and clumsy devices which, in spite of their age of some five hundred years, were still in the earliest stages of their development. His rockets, on the other hand, were just about as large and as powerful as a black powder rocket can be. Since he could not know this, it was only natural that his conclusions were wrong. Artillery soon began to outrange, outshoot, and out-perform rockets in every respect, and the later invention of the internal combustion engine made even the weight of the guns unimportant.

Congreve died May 16, 1826. Among his papers plans for a rocket with a diameter of 8 inches were found, as well as some notes relating to rockets weighing 500 and even 1000 pounds.

Congreve's influence was enormous. Denmark, Egypt, France, Italy, the Netherlands, Poland, Prussia, Sardinia, Spain, and Sweden attached rocket batteries to their artillery. Austria, England, Greece, and Russia had rocket corps which were independent units. So had Switzerland, but only on paper. The United States formed rocket units—there is some doubt whether they were independent or artillery units—some time later when William Hale had made a new invention which will be described shortly. At least twenty books on war rockets appeared during as many years, written in English, French, and German (the Russians wrote French at that time).

Congreve's war rockets gave rise to two or three useful and ten times as many useless inventions. And they are responsible for allusions which are still known to practically everybody, even though people do not know the reference any more. Everybody knows, for example, that one of the famous early locomotives was named the *Rocket*. No direct allusion to the speed was intended; the name grew out of an article in a British engineering journal. George Stephenson had promised a locomotive of twice the speed of a mail coach. And a critic exploded into words like "silly and ridiculous . . . twice the speed of a horse-drawn coach. It may just as well be expected that the inhabitants of Woolwich will consent to a ride on a Congreve war rocket than trust their lives to such a machine." Whereupon Stephenson called his new locomotive *Rocket*.

And every American sings about "the rockets' red glare, the bombs bursting in air . . ." which refers to the bombardment rockets launched in quantities against the bastions of Fort McHenry.



12. Late British War Rocket (1905).

An example of the stickless Hale rocket. 1.—Cast iron; 2.—Hardwood; 3.—Propelling charge; 4.—Steel tubing.

But it is necessary to finish the story of the military interlude first. All those rocket corps and rocket units did not live very long; by 1850 most of them were gone. The Austrian corps was not dissolved until it had failed badly against the Prussians in 1866. The British Rocket Corps had disappeared rather early as an independent unit, but war rockets continued to be an issue weapon in the British Colonial Services for a long time. They are still listed as such in the official *Treatise on Ammunition*, edition of 1905. (Fig. 12.)

The American war rockets as well as the later British war rockets of the Colonial Services were no longer Congreve rockets. As soon as the general construction of Congreve's rockets had become known to other technicians (after the first bombardment of Boulogne), they had decided that the heavy guiding stick should be abolished if possible. The stick was needed to keep the rocket from moving erratically, but it also looked like a lot of dead weight.

There were two possible ways to eliminate this dead weight. One was to find a substitute for it, some less ponderous mechanism which would perform the same service of keeping the rocket on a straight course. The other was to thrust another function on the guiding stick. French experimenters decided in favor of the latter method; they designed or at least drew pictures of war rockets where the projectile was elongated to the extent of serving as a guiding stick at the same time.

But the real solution was the first method, and William Hale, around the middle of the last century, succeeded in finding it.

It consisted of three small metal vanes placed in the exhaust nozzle, vanes which would make the rocket rotate furiously along its longitudinal axis, making it spin in the same manner a rifle bullet spins. The American rockets were Hale rockets and so were the late Colonial Service rockets of the British.

During the latter half of the nineteenth century quite a number of inventors, military and naval engineers as well as landlubbers, tried to invent rocket torpedoes. It was generally known through Robert Fulton's demonstrations in Great Britain and in America that an underwater explosion inflicted much more severe damage on a vessel than any above-water explosion could possibly do. The mine and the so-called spar torpedo had been invented and used rather extensively during the Civil War. It remained to create a real torpedo, to provide a mine with mobility of its own.

Some of these inventions were actually tested, but just as cannon soon outranged war rockets on dry land, mechanical torpedoes like the Whitehead soon outranged the rocket-propelled models. No rocket torpedo was ever actually used in battle.

But in the meantime the rocket had gained a place in naval life, although not as a weapon.

The life of a seaman often required something resembling shooting but less violent than real shooting. The Congreve rocket fitted perfectly into this picture. And in 1821 Captain Scoresby, on the good ship *The Fane*, began to hunt whales with rocket harpoons. It was a good idea and it is likely that rocket harpoons would have endured to this day if it had not been for the fact that a rocket is not quite accurate enough. Because of this the first real harpoon gun replaced the rocket harpoon.

But rockets could throw lines, and that feature was utilized. Small vessels the size of lifeboats that had to negotiate a heavy surf did so by using a rocket to throw a small anchor across the surf. Then they pulled themselves to safety along the anchor rope.

This method, of course, worked both ways and resulted in the most useful rocket invention that was to follow the Congreve war rocket.

This was the so-called lifesaving rocket, used to rescue the crews of stranded vessels. It works in this fashion: a rocket carries a thin line from the shore to the stranded vessel. By means of this thin line the crew of the vessel hauls a heavier rope across and leaves

the vessel one by one in a so-called breeches-buoy, a saddle-like affair suspended from the rope and pulled back and forth by means of thinner lines.

The first plan of this kind originated in the mind of a tradesman, the Prussian Master Weaver Ehr Gott Friedrich Schaefer. This was before Congreve, and Schaefer did not think of rockets; he wanted to shoot the first line from a small siege mortar. He drew up his plans and submitted them in 1784 to the commander of the artillery of Frederick the Great. A committee of ordnance officers was entrusted with the evaluation of the idea, but most of them seem to have known the sea only from books; they decided that the invention was impractical.

Thirteen years after Schaefer a British Lieutenant of the Royal Artillery by the name of Cell advanced the same suggestion. The performance was the same, with the minor difference that the idea was not actually rejected. Instead no action was taken. A few years later, however, George William Manby, Royal Military Inspector, witnessed the stranding of a ship on which 67 people perished in plain sight of the horrified but helpless spectators ashore. After that Lieutenant Cell's suggestion was revived, Manby himself constructed the mortar, and the invention saved 332 lives during the years from 1807 to 1823 on the coast of Norfolk.

When Manby's mortar proved successful the Prussians remembered Schaefer's suggestion and went to work building a line-throwing mortar. It was tried for the first time in the harbor of Pillau on the shores of the Baltic Sea and in July 1819 the provincial government officially permitted "the use of this new means of saving lives, although the Government is aware of the fact that this means might be dangerous in itself."

Meanwhile a Captain by the name of Treugrouse had substituted Congreve war rockets for the line-throwing mortar in private experiments made in 1807. The experiments were successful, but remained almost unknown until John Dennet of Newport on the Isle of Wight repeated them in 1824. It was Dennet who applied for and was granted the first British patent for such an apparatus. It is dated August 2, 1838. Four years after Dennet's first experiments the Prussian Major Stiehler demonstrated line-throwing rockets for the same purpose near Memel, using a Continental (possibly Polish) imitation of the Congreve rockets as a missile. Major Stiehler's experiments attracted much attention and led to

the introduction of that method on the European continent.

But the nineteenth century, which saw the rise and fall of the Congreve war rockets—both literally and figuratively speaking—could not draw to a close without witnessing attempts at revival of Hassan Alrammah's and Joanes de Fontana's old ideas about rocket-propelled torpedoes. Early in the nineteenth century Robert Fulton had built a small submarine and had demonstrated that an underwater explosion, because of the incompressibility of water, had greater power by far than the same explosion in air.

Fulton, in turn, had derived the germ of this idea from a book on physics, written in French but published in London in 1734. That book contained the description of an accidental discovery by its author, the French refugee physicist Doctor Desaguliers, during a pleasure trip on the river Thames. The party of which Desaguliers was a member amused itself with fireworks of various kinds, among them "water rockets," which are still manufactured by pyrotechnicians on occasion. Such a water rocket consists of a water-proofed cardboard tube weighed down at one end, to make it float in a vertical position. It is charged with alternating layers of strong and weak powder mixtures. The weak layers do no more than produce a shower of sparks when the rocket floats at the surface. The powerful layers push it down so that it reappears at another point when the next weak layer catches fire. The spectacle ends with the explosion of a small powder charge which goes off at the surface when the last layer is weak or under water when the last layer is powerful.

One of these water rockets happened to rise under the bottom of one of the pleasure barges when the last powder charge went off. Desaguliers emphasized how small it was, "much less than an ounce" (*beaucoup moins d'une once de poudre*, he wrote), but that small charge pushed the bottom of the barge in so that the people aboard did not even have time to change over to another boat which was very close, but fell into the river. Doctor Desaguliers conceived the right explanation at once, that because of the fast expansion of the powder gases the water acts like a solid body so that the bottom of a ship offers less resistance than the water does.⁶

⁶ "Dans l'explosion de la poudre, dont la vitesse, dans son expansion, est excessivement grande, l'eau résista comme un solide, et par conséquent la poudre se fit un chemin par le fond de la barque dont les planches étoient peu épaisses et moins denses que l'eau. . . ."

The submarine mine, based on this principle, was evolved (independently) by the Russians during the Crimean War and by Confederate engineer officers during the Civil War. The problem was to give mobility to these mines which, incidentally, were then called "torpedoes," the name which was later transferred to the mobile torpedo.

Several dozen torpedo types were invented and mostly tested during the forty years between 1860 and 1900, the only surviving type being that of the Scotsman Whitehead which is really a model submarine, complete with engine and steering devices. Some of the early rivals of the Whitehead torpedo, and the only ones which interest us here, were rocket propelled.

The first experiments of this kind of which we have definite knowledge were made in 1862 from a submerged caisson near Red Hook, in New York harbor. The experimenter and inventor of the device was one Major Hunt of the Engineer Corps, U. S. Army. His torpedoes had the shape of a projectile and consisted of three parts: a warhead filled with cannon powder or possibly guncotton, a powerful powder rocket for propulsion, and a wooden "shoe" which surrounded the rocket and carried inclined ridges supposed to produce rotation of the torpedo.

An 11-inch Dahlgren gun was used as a launching tube at first, but it was soon replaced by a specially constructed 12-inch tube with two sliding valves.

It was found that the direction was not very reliable but that the rocket torpedoes could be propelled in this manner for several hundred feet, which made it appear as if such submerged caissons would be a valuable adjunct to shore batteries in the defense of harbors and inlets. Unfortunately Major Hunt's experiments found a tragic end. Once, after the rocket had been ignited, it was found that the outer valve had not been raised. Major Hunt feared that the gun might burst and descended into the caisson. The gun did not burst, but the Major as well as an assistant who tried to come to his rescue were smothered to death in the caisson by the gases escaping around the rear valve.

But while this accident ended American experimentation with such a device, it did not eliminate the idea altogether.

Mr. Quick, an English engineer in the Royal Navy, somewhat later, proposed an invention on the same principle as Major Hunt's, and an experiment was recommended by the Royal

Engineer Committee, which took place at Shoeburyness in 1872.

The torpedo was a cylinder, something over 5 feet long, with a sharp-pointed head, and immediately behind it was a space intended to be filled with guncotton. The after part of the body consisted of four rockets, which were in communication with the igniting charge, and whose gas escaped on ignition through spiral vents designed to give rotation to the rocket and keep its axis steady while projecting it through the water.⁷

The invention was carefully thought out, as was the experiment devised to test it, but the latter turned out unlucky. As Lieutenant Barber put it in his lecture:

The torpedo was fired from a 10-inch gun, which was laid on the beach at about 5 degrees elevation, at a spot where the incoming tide would cover it to a depth of about 3 feet. The muzzle was closed by a disc of glass fixed in a wood washer tightly sealed round the edge, while an electric wire led through the vent of the gun to a small igniting charge in the centre of the base of the torpedo. When the tide rose and covered the gun the experiment took place. On firing, the torpedo burst open close to the muzzle of the gun, two rockets rising high into the air, one of which descended again almost immediately. . . . No further experiments have been made that I am aware of on Mr. Quick’s plan. . . .

William Hale, the inventor of the stickless rocket for land warfare, is known to have been opposed to the idea of a rocket-propelled torpedo. Hale pointed out that the main value of a torpedo consists in striking the enemy vessel below the waterline and exploding there. But this condition, he said, cannot be fulfilled in the case of a rocket-driven torpedo since the rocket, due to the steady combustion of its propelling charge, is steadily losing weight.

At about the same time when the British Navy made the single ill-fated experiment with Mr. Quick’s rocket torpedo an American engineer who is identified only as “Mr. Phillips of Indiana” submitted a novel idea for a rocket torpedo which was designed to circumvent the difficulty pointed out by Hale. Phillips’ rocket torpedo was really a torpedo-towing rocket. The exceptionally large rocket, 6 or 7 feet long and 1 foot in diameter, was to float at the surface, towing under water the comparatively small and gener-

⁷ Lt. F. M. Barber, *Lecture on . . . Torpedoes*, Newport, R. I., 1874.

ally cigar-shaped torpedo which was to be non-buoyant. "When the rocket strikes the enemy it explodes at the water's edge (carrying a separate bursting charge of its own) while the torpedo dives and is carried by its momentum under the ship where it explodes on striking the bottom." It seems that Mr. Phillips' rocket torpedo was never built and tested. It would have been interesting to see whether such a double explosion would have taken place in the manner predicted by the inventor. It would also have been interesting to see whether a rocket of such dimensions could have skimmed across choppy waves without being deflected from its course.

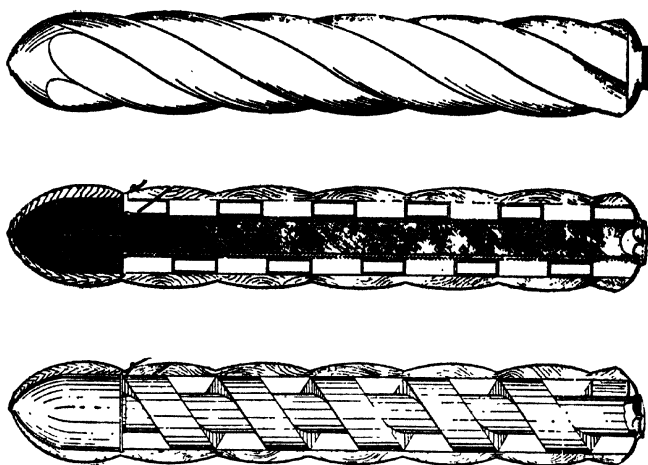
In 1873 the British Navy also experimented with another rocket torpedo, invented by Charles Meade Ramus. The first experiments were not very successful, but the inventor did not give up hope and improved his invention greatly so that he could demonstrate it with much better success again in 1879. According to a now defunct German military magazine,⁸ the torpedo traveled 15 feet below the surface with a speed of about 50 feet per second. Its range was about 1000 yards. The bursting charge consisted of gun-cotton. The torpedo also carried a device for cutting anti-torpedo nets. Ramus' offer was rejected again, however, because a range of 1000 yards was deemed insufficient.

It may be remarked here that the German Navy resumed experiments with rocket torpedoes as late as 1906 and continued them for several years, almost to the outbreak of the First World War. It is known that the rockets used had a caliber of 80 millimeters. The speed obtained was not revealed but it was stated that it was "much higher" than that of standard Schwartzkopff (the German modification of the Whitehead) and that the cost of such a torpedo was only slightly above 10 per cent of that of a standard torpedo carrying the same high-explosive charge. The experiments were discontinued because the rocket torpedoes were too erratic and might have endangered friendly vessels if used in action.

To return to America, Fig. 13 shows the rocket torpedo submitted in 1874 by Lt. F. M. Barber for a contest. Another entry received only weeks earlier was the rocket torpedo of "Mr. Weir, a civil and mechanical engineer of New York." Because Mr. Weir had a slight priority and also because his design was supported by experimental evidence it may be mentioned first.

The inventor stated that the over-all length of his torpedo would

⁸ *Archiv für die Offiziere der Ingenieur und Genietruppe*, vol. 85.



13. Lieutenant Barber's Rocket Torpedo.

Among the many efforts of the late nineteenth century to produce self-propelled torpedoes were a number of rocket torpedoes. Lieutenant Barber's type represents one of the more complicated designs.

be 7 feet 7 inches, the diameter 12 inches. The rocket composition was to weigh 78 pounds, the explosive charge in the head 74 pounds, the over-all weight was to be about 245 pounds. The inventor also reported on tests privately undertaken by him. The rocket torpedoes were fired under water, 4 feet below the surface, and aimed at a line 4 feet below the surface on a target 63 feet distant. They struck the target after 4.5 seconds, 5 to 7 inches below the 4-foot line at which they were aimed.

At the same time as Mr. Weir, Lt. F. M. Barber, from whose published lecture many of the preceding data and Fig. 13 have been taken, submitted plans for a rocket torpedo of his own to the Bureau of Ordnance. The length of the device (which apparently was never built) was to be 7 feet, the diameter 12 inches, with a displacement weight of 287 pounds. The rocket charge was to weigh 51 pounds, the bursting charge 48 pounds.

A tube containing rocket composition formed the center of the torpedo. Around it was wound a light metal spiral tube which could hold 52 pounds of water. The water, which, of course, had the purpose of replacing the weight of consumed rocket composi-

tion, was to enter in front. The rotary motion of the rocket, brought about by the shape of the outer wooden cover, would keep the water at the outer walls of the spiral tube, while the shape of the tube would make the water flow toward the rear so that, at least theoretically, it would not only replace the weight of the consumed rocket composition but would also locate itself approximately where the composition had been consumed, and at the proper rate. The ignition of the torpedo was to take place by way of a percussion fuze, set off by the impact on the enemy vessel. But the rocket charge was to ignite the bursting charge at any event when it was exhausted so that torpedoes which missed would not constitute a danger.

Although rockets had been expected by some to play an important role in the First World War, actually they hardly put in an appearance, save for their use as signals. The Germans made some use of large powder rockets by sending them across barbed-wire defenses. The rocket carried a small boat anchor and the barbed-wire entanglements were pulled out by the roots in hauling the anchor back. The Russians as well as the French used powder rockets, attached to the upright struts of their biplanes and ignited electrically from the cockpit, to set fire to German observation balloons. But aside from these isolated cases no war rockets appeared then.

Chapter 4:

PROPHETS WITH SOME HONOR

It is not the gray, cold, naked objective truth that counts in the history of mankind and will advance the cause of civilization, but it is the flight of human imagination, the impulses and visions of a genius, very often his errors and miscalculations, which have stimulated inventions and progress.—Berthold Laufer in The Prehistory of Aviation.

The history of science is science itself, the history of the individual, the individual.—Johann Wolfgang von Goethe in Mineralogie.

PARALLEL to the story of the use of rockets there runs another story: that of the application of rocket power to machinery in general and to vehicles in particular. No systematic attempts were made prior to the days when Professor s'Gravesande astonished his pupils by demonstrating a steam-spitting small vehicle that scampered across the floor.

Consequently some of the early instances in that story stand alone in splendid isolation in space and time.

The earliest of all seems to have been the apparatus which later became known as the Flying Pigeon of Archytas, dating back to about 360 B.C. For many centuries the wooden pigeon has been praised as one of the most ingenious inventions ever made by man and practically every writer who praised it added that the secret had been lost. While the praise was justified in view of the early date, the lament was not. A Roman author, Aulus Gellius, had described it quite clearly, clearly enough to permit its reconstruction.

According to Aulus Gellius the pigeon of Archytas was suspended from strings with counterweights "which preserved the equilibrium and the pigeon was propelled by the blowing of the air mysteriously encased therein." This means that the wooden bird model did not fly at all, as is usually asserted, but that it merely moved in circles around the point of suspension, motivated by air blowing from its body. If such a model were to be constructed today, the simplest way of accomplishing such a performance would consist in placing a small container of compressed air inside

the body. Archytas must have used another method, easier to handle with the means at his disposal. In all probability he used steam, unless all the descriptions we have are misleading, and it may be assumed that the bird model was moved around by the reaction of a steam jet.

This would make it an earlier edition of another ancient invention, models of which are still shown and operated in elementary physics classes: the aeolipile, invented, according to tradition, by Heron of Alexandria.

Unfortunately we don't know just how the original aeolipile looked. Nor do we know just when it was invented. The one definite clue is that the inventor, Heron, is stated to have been a pupil of Ktesibios. Just to make things easier there was more than one Ktesibios, but Heron's teacher most likely was *Ktesibios mechanicus* who lived in the third century B.C., fairly soon after Archytas.

The aeolipile probably consisted of a bowl-shaped container which was filled with boiling water and then placed over the fire on an altar. The steam rose through a tube into a spherical chamber and escaped through two narrow tubes bent backward near their tips. The reaction whirled the tubes and the spherical chamber around as long as fresh steam came from the boiler. (Fig. 14.)

About two thousand years after its original invention, a physicist by the name of Segener had the idea of turning such an aeolipile upside down and forcing water into it under pressure. This invention is now in general use—turned right side up again—and known to everybody as a rotating lawn sprinkler.

Another such isolated instance of the application of rocket power is a story which may be legendary or it may be true—there is no way of telling. It centers around the otherwise completely unknown person of a Chinese official whose name is given as Wan-Hoo.

This Wan-Hoo, the story goes, committed a rather spectacular suicide in or around A.D. 1500 by inventing and testing a rocket airplane. He took two large kites and connected them with a framework in the center of which a saddle was fastened. Forty-seven large powder rockets had been attached beneath the kites in strategic places and forty-seven coolies stood ready with flaming torches to ignite these rockets at a prearranged signal. When everything seemed ready, the learned and daring Wan-Hoo seated himself in the saddle and finally signaled to the waiting coolies. They rushed at the machine, each one applying his torch to the rocket



14. Heron's Aeolipile.

he was to ignite, and Wan-Hoo and his machine disappeared in a noisy cloud of black smoke.

Precisely the same can be said about the second known attempt to combine the principles of flight and of propulsion by reaction.

In 1782 the Montgolfier brothers succeeded in making their first hot-air balloons rise. Just one year later two Frenchmen, the Abbé Miollan and one Monsieur Janninet, announced that they had solved the problem of making such balloons fly in the desired direction. Their idea was simple. The bag of the balloon was filled with hot air or smoke which had the tendency to expand if permitted to do so. If there were a hole in the side of the bag the hot air would escape through that hole, naturally causing a reaction in the opposite direction which would propel the balloon sideways. All that was required was to have several holes around the circumference of the bag, kept shut by valves which could be operated from the gondola.

It was decided to make the first attempt with a balloon which had only one exhaust hole. Subscriptions for this balloon were offered and were sold to an eager populace. The ascent, of course, was public and, equally of course, an admission was charged for the privilege of witnessing the epochal event.

The balloon was ready in midsummer 1783, the attendance was good, but Miollan and Janninet had the particularly tough luck to pick a day which turned out to be unusually hot. Because of that the most frantic stoking resulted in only a partial inflation of the bag. It looked weak and wrinkled and did not even have enough lifting power to lift itself and the gondola, to say nothing of two passengers. Finally two things happened almost simultaneously: the balloon burst into flames and the spectators lost their patience which was strained by the hot weather anyway. They rushed to the balloon and tore off smoldering pieces to be kept as souvenirs, shouting, meanwhile, for the two unlucky inventors.

Janninet merely disappeared, it seems, while Abbé Miollan proved a little more resourceful: he grabbed the box containing the admission money and left Paris with a speed that by far surpassed anything he had promised as the probable speed of his balloon.

The third attempt at rocket flight ended even more ingloriously: it was forbidden by the police.

In the early decades of the nineteenth century there lived in Paris a rocket maker by the name of Claude Ruggieri, obviously an Italian. It was a period which was full of stories of balloon ascents on the one hand and of Congreve war rockets and their exploits on the other hand. Ruggieri profited from the news by staging demonstrations in which small animals like mice and rats were carried aloft by large rockets and brought back to earth safe and sound by small parachutes.

Claude Ruggieri's rockets grew in size and power and around the year 1830 the resourceful artisan announced that a large combination-rocket, as it was called, would carry a ram aloft. On the day after the announcement Ruggieri received an offer from a young man who wanted to take the place of the ram. Ruggieri accepted the offer and the rocket ascent was announced to take place on a certain date from the *Champs de Mars*. But the police intervened, probably because the "young man" turned out to be a small

boy. I don't know whether the whole project collapsed because of this or whether Ruggieri used his ram after all.

Dr. Robert Paganini of Zweisimmen, Switzerland, informed me several years ago that the boy's name was Wilfried de Fonvielle who must have been at the most eleven years of age when he offered his person for the venture. Later on he became a balloonist and was one of those who left Paris by air when the city was besieged by the Prussians in 1871. Wilfried de Fonvielle died in 1914, just a little over ninety years old.

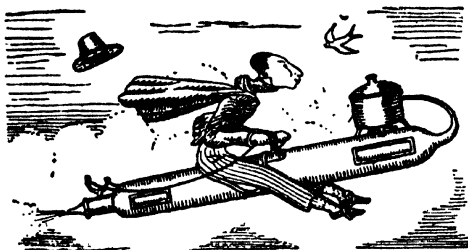
In 1843 the daily press of Russia devoted a great deal of space to the invention of one Emil Jir who claimed to have solved the problem of the dirigible balloon by the invention of a mechanism which would permit balloons to find favorable winds by rising or falling, without the necessity of sacrificing either ballast or lifting gas. The mere mention of this project brings to mind the *Five Weeks in a Balloon* of Jules Verne, but Verne's and Emil Jir's methods were not alike. Jir planned to accomplish the rising and falling by means of reaction; he wanted to carry compressed air along for this purpose, probably also a hand-operated compressor. The modern verdict on this idea would be: "theoretically sound but quantitatively insufficient."

This verdict applies to most of the "daring inventions" of this type.

Six years after Emil Jir, a member of the engineer corps of the Russian Army submitted a manuscript of 208 pages to the Governor of the Caucasian provinces, Prince Vorontzov in Tiflis. The manuscript had the title: "On the methods of guiding an airship," and was signed by "Engineer Tretesskij."

Tretesskij planned to equip the airship with exhaust nozzles pointing in all directions; if movement in a certain direction was desired, the proper nozzle was to be connected with the "blast generator," to use a modern term. The blast was to consist of compressed air or steam or, possibly, of air heated by an alcohol blowtorch.

Both these projects may have been influenced by a British patent which had been granted on January 4, 1841, to one Charles Golightly. Unfortunately the patent itself is lost and no description or picture of Golightly's project is known. All we do know is a cartoon on Golightly's project which bears the jeering title: "Steam-



15. Caricature of Golightly's Projected "Aerial Steam-Horse."

Horse, on which one may ride in one hour from Paris to St. Petersburg." If the caricaturist expressed the idea correctly the Golightly project was a steam reaction airplane. (Fig. 15.)

Strangely enough, this cartoon had more influence than the original invention. It set quite a number of people to thinking about reaction planes. A few short paragraphs from a German book seem to express the state of mind of the leading mentalities of the middle nineteenth century quite significantly.

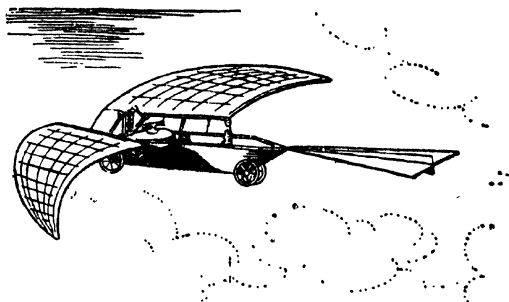
In the diaries of my mother, Elisabeth Lepsius, née Klein, I find under the date of November 12, 1846, a description of a house party where a friend of the family, the naturalist Ehrenberg, was one of the guests. He was the famous professor Christian Gottfried Ehrenberg (1794-1876) whose discovery of the *infusoria* had populated all the waters and even the air with the smallest living things then known.

After talking about Ehrenberg's own line of research:

a great deal of the conversation was devoted to guncotton. Ehrenberg was highly excited about the discovery and declared that it would exert an enormous influence on the development of aviation and that we would soon come to the point where we are able to propel airships vertically as well as horizontally by means of rockets.¹

Guncotton, it may be explained here, had been discovered just one year earlier (1845) by the German chemist Christian Friedrich Schönbein who had tried to dissolve cotton in a mixture of nitric and sulphuric acids. Of course the cotton had refused to dissolve

¹ B. Lepsius in *Lili Parthey, Tagebücher aus der Berliner Biedermeierzeit* (Berlin, 1926).



16. German Drawing of a Rocket Airplane.
Said to be by Werner von Siemens some time from 1845-55.

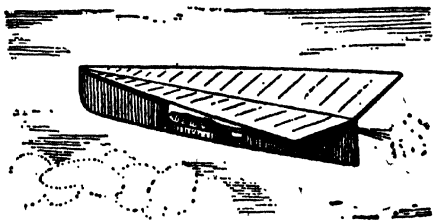
and Schönbein, writing off the experiment as a failure, had gone home for supper, after putting the still wet strands on top of the hot stove to dry. Schönbein lost his laboratory that way, but discovered guncotton in the process.

Another well-known man who became interested in the idea of guncotton-propelled airplanes was Werner von Siemens, the founder of the enormous Siemens Works near Berlin. Siemens drew a sketch of such a plane and had it published. Because he was then holding an army commission he did not use his name but labeled the sketch "a proposal coming from an officer." (In Russian books on rockets this project is erroneously ascribed to a Nuremberg mechanic by the name of Rebenstein.) (Fig. 16.)

And finally there was the Phillips helicopter. Phillips built a functioning model, running on steam. It was, in fact, an aeolipile with helicopter blades. The model was demonstrated to learned societies in Paris in 1842 and it worked. According to contemporary descriptions, it was made of metal and weighed around two pounds, the center of the apparatus being, of course, the boiler. The rotor had four blades, tilted at an angle of 20 degrees and supported by four struts. The four exhausts of the aeolipile part were connected with these four struts. The reports do not give figures about the performance, but state that the small helicopter "rose to considerable height and traveled a long distance horizontally until it touched the ground again." As in the case of the Golightly patent, the demonstration of the Phillips helicopter gave rise to a caricature. (Fig. 17.)



17. Cartoon of a Helicopter (about 1860).

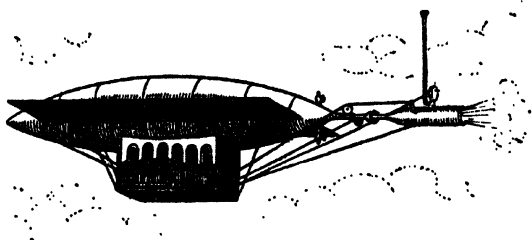


18. Steam Reaction Airplane of 1867.

Three other names that have to be added to the list of the early inventors of rocket-propelled aircraft are those of General Russell Thayer of Philadelphia, of engineer Nicholas Petersen of Mexico City, and of the inventor Sumter B. Battey. The dates are, in the same order, 1884, 1892, and 1893. All three inventions relate to the propulsion of elongated airships, not round balloons.

General Thayer had, of course, a military application in mind. His airship was a war vessel, equipped with cannon. Propulsion was to be accomplished by a jet of compressed air, and the air was carried along in steel cylinders, but the compressors were stationary on the ground.

The other two suggestions were fairly much alike in several respects. Nicholas Petersen equipped his vessel with a mechanism closely resembling the old but then very common Colt revolver



19. Battey's Rocket Airship.

except that it was much larger and large rockets were to be used instead of cartridges.

Sumter B. Battey, who was granted a U.S. patent on his invention, had a more machine-gun-like mechanism in mind. His reaction motor worked with a large number of small explosive fills which were fed into the chamber automatically. (Fig. 19.)

In judging all these ideas and projects, one thought has to be kept paramount. The choice of rocket or steam reaction as a means of propulsion was not a free choice, it was a matter of necessity. No other prime movers except the steam engine and the clock-work existed then. The one was obviously too heavy and the other was, equally obviously, too weak. Rockets, on the other hand, had proven successful in certain applications and, as long as there was no proof that they could *not* perform as a prime mover for aircraft, they were worth considering.

It was precisely this kind of reasoning which caused the conception of a project that, because of the circumstances under which it was born, remained unknown for more than thirty years. It was safely locked away in the archives of the Imperial Russian Secret Police.

The inventor was one Nikolai Ivanovitch Kibaltchitch and the invention had been made, or at least put on paper, in a cell of the Peter-Paul Citadel while the inventor was awaiting the day of his execution.

Nikolai Ivanovitch Kibaltchitch was one among six members of the *Narodnaya volya*, the revolutionary party called "Will of the People," who were charged with the "major crime," the assassination of Czar Alexander II. The trial took place at St. Petersburg, then capital of the Russian Empire, from the 7th to the 9th of

April 1882, ending, as was to be expected, with death sentences for all except one of the defendants who was a woman.

The leader of the group was Alexander Shyelyabov who, when in court, would not miss any opportunity of inserting a political speech into the record. The actual assassin, the man who had thrown the bomb that killed the Czar, was one Nikolai Ryssakov, a young man who was extremely nervous all through the proceedings and hysterically voluble when asked to answer a question. Kibaltchitch had taken part in only one respect: he had made the bombs and had instructed Ryssakov and others how to use them.

Kibaltchitch had been arrested on March 29, 1882. Two days later he had been confronted with Ryssakov who recognized him at once as the bomb instructor. According to court procedure an attorney was then assigned to defend him.

When the attorney went to Kibaltchitch's cell on one of the first days in April, he probably expected to find either a fanatical revolutionary or the proverbial broken-down offender. What he actually found was a well-dressed, quiet young man who was deep in thought when the cell door opened. But Kibaltchitch did not think about his personal fate, which he knew was decided; he was busy inventing a rocket airplane. Literally his first question was whether his attorney might be able to obtain permission for him to write in his cell.

The attorney realized soon that the case was hopeless from the legal point of view. Kibaltchitch not only refused to go through the legal routine, he also did not comply with any of the established rules. When in court he sat as if he were paid for attending, but were not obliged to listen to the proceedings. He came to life only when the explosives experts were called to testify. Then he would enter into a discussion, argue about fine points of the manufacture of a detonator, ask questions about facts which he had failed to find in literature, and be deeply gratified when the experts asserted that the bombs he had made had been good, professional, reliable bombs.

He also called public attention to the fact that he had just finished a manuscript which bore the title "Preliminary design of a rocket airplane" and that he had asked his attorney to submit it through the prison authorities to a committee of technical experts.

That had actually been done, but the manuscript had not gone beyond the prison administration. The officials in charge decided

that a public discussion of Kibaltchitch's manuscript would stir up too much interest in the person of the defendant—the newspaper accounts of Kibaltchitch's short remarks in court had done too much harm already in their opinion. The manuscript was simply attached to the documents of the trial and locked away in the archives, until the latter were systematically searched by the Tcheka in 1918. It was then published, with comments by historians and engineers, in the Russian journal *Byloje (The Past)*, October-November 1918.

Kibaltchitch had visualized his rocket airplane as a platform with a hole in the center. Mounted above this hole was a cylindrical explosion chamber into which "candles" of compressed powder were to be fed. The apparatus was to rise vertically at first, then the chamber was to be tilted for horizontal motion; the speed was to be regulated either by the dimensions of the powder "candles" used, or by their number.

Kibaltchitch died in the belief that a committee was still debating his plans.

None of all these inventors of rocket aircraft thought of his projected vehicle as a possible means of leaving the earth. Although this idea had been voiced in novels by that time, as we have seen, it was still not a subject of serious consideration. But the first project for a rocket-propelled vessel for ascents beyond the outer layers of the earth's atmosphere was not long in coming.

As such things often go, the idea was conceived by two men almost simultaneously, two men of different backgrounds and different characters, of different habits and different nationalities.

Both were strange and, each in his own way, colorful characters. Both were independent in their thoughts and stood alone with them. Both were, which is also interesting, self-taught and both failed to be very successful. But their similarities end with these statements; everything else about them was different. The Russian school teacher Konstantin Edouardovitch Ziolkovsky (pronounced *Tsee-oll-kóvs-key*), handicapped by the same physical ailment that did not handicap Thomas Alva Edison at all, lived a long quiet life in a rather unimportant and, to the outside world, practically unknown corner of the Russian Empire, near Kaluga. The German law student Hermann Ganswindt, who never got to be a lawyer or a judge as his parents had dreamed he would be, also lived a

long life, but a stormy one, battering his way through almost four-score years in a manner which could not possibly be used as a plot for a story. Any self-respecting editor would reject it as "unnatural and improbable."

Of the two, Ganswindt was more impetuous and less scientific. And, since he was Ziolkovsky's senior by the narrow margin of one year, I'll begin with him.

He was born in a small town in East Prussia on June 12, 1856. His parents, well-to-do people, decided that little Hermann was to study law, acquire a doctor's degree, and then settle down to a successful and "reputable" life in the legal profession. Filial rebellion was not a part of the program, but young Hermann rebelled. He decided in an upsurge of revolutionary spirit that "justice" and "right" were not always identical, and this decision quickly condensed into the belief that the courts by administering the law could not do other than dispense "injustice and law" instead of "right." Hermann Ganswindt wanted no part of that, and he wrote a book about his worries, or rather a book in which these worries were expressed vehemently along with other things. It was thoroughly misunderstood, of course, but Ganswindt would never admit that he had written a book which could be misunderstood; he only blamed the others for not understanding it.

Having turned his back on the legal profession, Ganswindt turned toward his real love: mechanical gadgets. All his inventions had to do with transportation in one form or another. He invented (not in that order): bicycles, horseless carriages, "motor" boats, fire engines, airships, and spaceships. Some of his inventions remained on paper, but most of them were actually built; in the majority of cases the inventor was his own craftsman.

His first attempt was the airship. There were some airships on record at this time: Giffard in Paris had built one with a small steam engine in the gondola (it was too weak). Dupuy de Lôme, also in Paris, had made one for propulsion by muscle power. Hänlein had completed an airship in December 1872, and it had been the largest of the three—all of 165 feet long. Ganswindt wondered why they had all been unsuccessful and found an answer which he incorporated in a patent that was granted to him in 1883 by the Patent Office in Berlin. (It was D.R.P. No. 29014.) The main mistake, according to Ganswindt, had been the semi-logical

idea that you had to build a small airship before you could build a large one.

In the case of the airship that was wrong, said Ganswindt. In order to be really a "dirigible," a ship must be able to maintain some 30 miles per hour. Nothing less would do or any breeze could change the dirigible back into a free balloon. Adequate speed would require an engine of at least 100 horsepower, but a steam engine—there was no other kind—of such power would be too heavy for an airship. Too heavy, that is, unless you built an airship of sufficient size; natural laws see to it that things improve with size in that case. If you enlarge a given airship ten times in every dimension, its volume and hence its carrying capacity are a thousand times as large as before. But its cross section and its air resistance are only ten times as large. *Ergo* an airship will become a true dirigible if only you make it large enough. The proper size for a 100 horsepower ship would be a length of 500 feet with a diameter of 50 feet.

His reasoning was somewhat crude as far as air resistance is concerned, but essentially he was right—such a ship could have been built then. Everybody knew, of course, that airships would have a great military value if they could only be built, hence Ganswindt submitted his ideas, copy of patent attached, to the Minister of War. The answer came quickly. It was no.

In retrospect we can only say that Ganswindt's conception of the problem was sound. But that was not so obvious to his contemporaries. Besides who was that man Ganswindt? Oh, a student of law who had interrupted his studies before he was even half-way through. And now he wants to be an inventor and travel through the air, the crank, and not only that, but he wants to travel through the air with structures twice the height of a church steeple. Ridiculous! If the small airships did not work how could a large one be any better?

Ganswindt had expected something like this. He wrote a book devoted exclusively to the problem of the dirigible airship, had it printed at his own expense, and submitted his suggestion again, this time accompanied by a copy of the book. But the Ministry of War was thoroughly weary of airships. The Ministry of War, the officers in charge said to themselves, has funds to buy inventions which are of military usefulness. But it has no funds to smooth

the way for inventions that at present are only projects. Anyway, the best military inventions have been made in the research laboratories of the Army and not by outsiders. Besides, if we grant funds for the invention of a dirigible today, we will get somebody else tomorrow who wants to have a cruiser with full complement in order to catch the Great Sea Serpent. Again the answer was no.

But Ganswindt had mailed copies of his book to everybody in the social register by then. Among the recipients was, of course, the Crown Prince, the same who was to rule later for 99 days as Kaiser Friedrich III. The Crown Prince was interested in intellectual matters; he also was dutifully interested in military matters. He read the book, he agreed with Ganswindt, and he ordered that an investigation be made.

The Ministry of War was displeased, not openly, of course. Ganswindt again! The officers in charge suddenly hated their high positions. The Crown Prince had ordered that the matter be looked into. The technical experts questioned agreed with Ganswindt. And Ganswindt, if rejected, might scream in print. The officers felt a triple noose around their necks; whatever they did was bound to be wrong. Japanese officers in the same position would have committed honorable suicide. The Prussians suddenly remembered that there was such a thing as diplomacy.

"To Hermann Ganswindt, Inventor: Sir, with utmost regret we beg to state that airships of a length of five hundred feet far surpass military requirements."

The Crown Prince, poor of health, was satisfied. Too bad, it had sounded interesting. The War Ministry was rid of Ganswindt, but they had rounded one cliff only to run into the next. Only a few years later they got another airship, projected by Ferdinand Graf Zeppelin. That was worse. Count Zeppelin was, in the first place, nobility. He was wealthy too. He had lived for quite some time in America which made him a widely traveled man. He had served as a colonel in the cavalry during the Franco-Prussian War and the records said that he had distinguished himself in an extraordinary manner. But the War Department had laid down its rules; Zeppelin received a "no" too. He was not accepted until he had spent his own money and that of a few wealthy friends proving the possibility of airships by building them.

Before Count Zeppelin's first ship was even completely designed, Ganswindt had become a well-known character in Berlin, delight-

ing in being called the "Edison of Schöneberg." He had founded a small factory for his inventions, combined with a permanent Ganswindt Exhibit with all the characteristics of a Fair, including large and brightly colored posters all over Berlin. The factory built a free-wheeling mechanism for bicycles and a new type of wheel hubs which were advertised as "practically frictionless." The factory built what Ganswindt called the *Tretmotor*. It was an engine ersatz, consisting of an ingenious arrangement of levers and pieces of rope. Two small platforms, slightly larger than a man's foot, were on top or behind the mechanism. The driver stood on these platforms and by alternately shifting his weight from one leg to the other made the mechanism whir. Ganswindt built a well-functioning "motor" boat that was propelled in that manner—he added a small artificial lake to his Fair for demonstrating it—and he built a carriage for two people, with the driver standing behind them. It worked well and Ganswindt rode around in it in the city. The result was astonishing; all other carriages followed him to see how it worked and after two or three rides the police asked Ganswindt to announce every trip in advance to them so that they could take the proper measure. Traffic was too much disturbed by the unexpected appearance of his horseless carriage.

The Fire Department of the City of Schöneberg accepted a carriage of that type for its own use, on trial. This was in 1894. It ran for several months and the reports were more than enthusiastic. Ganswindt felt that he could make the fortune required for the airship by manufacturing such cars. But then it was returned to him, still accompanied by reports praising its performance to the skies. But the Fire Department could not pay 4000 marks; it offered 2000. Ganswindt replied that this first model had cost him more than 2000 marks and took his carriage back. It did not occur to him that the cost price of later cars would be much lower; he had no sense for business, he only demanded his "right." And his "right," in this case, was to make a profit from the first carriage on. When I asked him later why he had not accepted the price offered to him, since that would have resulted in more orders and later profits, he failed to understand my reasoning. "But I would have lost money on that car," he insisted. "If, as you say, later cars would have cost less money to build, and I agree with you on that, I would of course have reduced the sales price."

In between he built a large helicopter with seats for two people.

The machine lacked only the motor, nothing else. Newspaper reports said that there was an internal combustion engine of sufficient horsepower on display at the Paris Fair. Ganswindt went to Paris and offered to buy the motor, provided that it developed the necessary power. That was promised and weeks later a crate arrived at Schöneberg. Ganswindt tested the motor and it lagged by a full third behind the promise. He returned it and thought about a way out. He found one. The helicopter had been assembled around a central axis; Ganswindt replaced the central axis by a length of steel tubing. Through this tube he threaded a steel rope which was attached to the ground as well as to the projecting roof of the factory building. Then he wound a second rope around the central tube and attached it to a heavy weight which, when released, would drop into a well dug for this purpose. It was an adaptation of the well-known trick of winding up a top.

The helicopter actually flew with two people in it. Not high, because of the short duration of the impulse it received, but it flew. And one of the early inventors of the movie, Max Skladanowsky, took a film of the performance. Together with other similar "shots" it made one of the first newsreels. The film was taken in June 1901 and the newsreel was shown in the *Wintergarten* in November of the same year. I have seen a copy of the program for the night of November 5, 1901. The last feature of the program was *Max Skladanowsky's Biograph* and one of the features of the Biograph newsreel was Hermann Ganswindt's Flying Machine.

By then Ganswindt had many enemies who claimed that the wire rope through the central tube was actually used to pull the flying machine up. Actually its purpose was to prevent side slips and accidents. The enemies also stated that "any blacksmith can duplicate the contraption at an expense of 500 marks." Ganswindt's friends replied with a bond of 35,000 marks, to be paid to the blacksmith who did. Nobody ever claimed the money. Ganswindt's enemies dug up yellowed copies of his first book with its indiscreet remarks about justice and right and "proved" that he was a Social Democrat in disguise. Ganswindt produced a testimonial about his helicopter, written by Count Schlieffen, the implication being that Count Schlieffen would not support a Social Democrat.

The fight ended dramatically in April 1902. A high official of the Police Department informed Ganswindt that he would like to see

the helicopter himself the next morning. Ganswindt was up early on that morning of April 17, 1902, in full dress with top hat, expecting the visitor. The visitor did not come; instead a plain-clothesman appeared with a warrant for Ganswindt's arrest. Three days later he learned why he had been arrested: he had accepted money from trusting investors in order to build things that were impossible to build. Since he had often displayed a sufficient knowledge of physics and chemistry to know that such things were impossible, he was guilty of fraudulent claims.

The trial, which included a court visit to Ganswindt's exhibits, ended with acquittal, but as far as public repercussions went Ganswindt might as well have been convicted. The company that rented poster space refused his posters, the newspapers refused his ads.

Ganswindt, embittered and hurt—all the more hurt, probably, because he felt that he was not entirely blameless—went berserk and turned against his numerous enemies. Ironically he turned against them by dragging them into court. If the world consisted of injustice he would administer some injustice too. The courts were embarrassed. There was a grain of justification in these lawsuits, but more often than not it was too slight to be noticed. The courts dragged the proceedings out—and Ganswindt complained to higher courts. The storm was completely quieted only by the war. Then Ganswindt turned to the Ministry of War again, offering his airship once more and stating loudly that the Zeppelin ship was an inferior imitation. He asked the Ministry for a sum of several millions as damages for the suppression of his invention, but promised that he would use the money to build his airship and put it at the disposal of Germany.

It was the German Minister of War—von Stein was his name—who voiced the general sentiment in one sentence. When, in 1917, another one of Ganswindt's innumerable petitions arrived, he wrote in red pencil on the cover page: "*Lebt denn dieser Unglücksrabe immer noch?*" ("Is that bird-of-woe still among the living?")

He was correct in the sense that Ganswindt, the Ganswindt of 1917, was no longer the Ganswindt of the period from 1883 to 1901. He was no longer an inventor who wanted to create something; he was a quarrelsome person who fought only to redeem an injustice done to him. He wanted it redeemed with money and public recognition. He wanted to hear "officially" what he put on

his stationery and envelopes: "Hermann Ganswindt, original inventor of the free-wheeling mechanism, the automobile, the airplane, the airship, and the spaceship."

He did get some kind of recognition in the end. Articles about him began to appear in newspapers and magazines and the general feeling was that he had been condemned too hastily. Some people even sent him anonymous gifts of money when they learned that the monetary inflation had left him impecunious and that he was supported by welfare agencies and by the elder of his twenty-three children. And in 1934 a semi-official government agency sent Dr. Stark with a gift of 1000 marks to Ganswindt.

Ganswindt was sick with a cold on that day and received the money and the official recognition which he thought it implied—actually it was one of the Nazis' propaganda gestures intended for domestic consumption—with deep gratitude. A week later he died (October 25, 1934). He had lived to fight for recognition; recognition achieved, he had nothing left to live for. He had received his "right."

Ganswindt received his long-awaited share of public attention in the late Twenties and early Thirties because of one of his early "inventions" to which he himself had never paid much attention: his conception of the spaceship.

It was actually the first I know of. I have seen the program of one of his lectures, delivered at the *Philharmonie*—the name indicates a concert hall in Berlin—on May 27, 1891. It was during this lecture, which was devoted mainly to aviation, that Ganswindt expounded his theory of the possibility of space travel.

Fairly early in his career he had come across reaction as a means of propulsion. He had realized that a reaction has to work in empty space. But while he intuitively grasped that, he never quite understood the mathematics of the problem, as I later discovered through much questioning. It was his contention that a gas jet could not produce reaction of sufficient magnitude, that it was necessary to throw off solid bodies, weighing at least two or three pounds apiece. Because of this preconceived notion, his "fuel" consisted of heavy steel cartridges containing a charge of dynamite. He wanted to feed those cartridges into a bell-shaped steel explosion chamber. One half of the cartridge would be thrown out by the explosion of the charge inside; the other half would hit the top of the explosion chamber and, after transmitting its kinetic

energy to the chamber, drop out. The chamber was rigidly connected with two cylindrical fuel drums on either side.

This assembly constituted the "motor." The passenger cabin was suspended from the motor on springs to ease the shocks. Naturally it was provided with a center well through which the steel pieces could pass. Once a sufficiently high velocity was reached, Ganswindt wanted to stop feeding cartridges into the explosion chamber. Then, he knew, the passengers would undergo the experience of apparent weightlessness which he wanted to combat by rotating the long and cylindrical cabin around its center well. This way he planned to substitute centrifugal force for gravity, making the two ends of the cabin the floors. That idea was correct too, but Ganswindt lacked either the ability or the patience—probably both—to work the plan out in detail.

Now for Ziolkovsky, the other early spaceship inventor.

Unlike Ganswindt, he was a patient and quiet man. Unlike Ganswindt, he never overlooked a single detail. Unlike Ganswindt, he never had any enemies. And unlike Ganswindt, he had considerable trouble speaking about himself and his work. When, about 1930, Professor Nikolai A. Rynin of Leningrad wrote to Ziolkovsky for a complete autobiography for his forthcoming seventy-fifth birthday, he received only a thin manuscript of a few pages, accompanied by a letter stating: "this, Nikolai Alexeyevitch, is the best I have to offer." Ziolkovsky also enclosed a collection of photographs and it is typical that he did not even mention the fact that he got married in his autobiography, although some of the later photographs show him surrounded by grandchildren.

He was born September 5, 1857, at Ijevsk in the District of Ryasan. His father was a forester by profession and an unsuccessful inventor and philosopher by avocation, while his mother came from a family of artisans. Ziolkovsky remembered these facts and he also remembered that his first toy, which he got at the age of eight or nine, was a small balloon, a rare toy in those days. Soon after, at the age of ten, Ziolkovsky got dangerously ill with scarlet fever which caused deafness; his hearing never returned. "At eleven I wrote the foulest verses."

His deafness made it difficult for him to attend school—even for what little schooling there was in Ryasan in 1870—but he

studied zealously, especially elementary mathematics and physics. Even that was difficult because there were only "a few doubtful books." But he managed to absorb the basic principles of science and those few fundamental facts he could find in the books he had. He not only satisfied the small requirements of a pupil; soon afterward he even satisfied those of a teacher and began to teach in 1876. In 1882 he was offered a position at the school in Borovsk in the District of Kaluga, and ten years later he became a teacher at the school of Kaluga, a position he held until he resigned because of ill health in 1920.

Most of the time he got up at dawn, went to school, and hurried home as quickly as possible to do his private work. The latter mainly concerned problems in physics, but he also worked on some inventions. At the age of twenty-three he submitted a few scientific papers to the St. Petersburg Society for Physics and Chemistry.

When his papers were received there they caused not a little consternation; the reaction was partly incredulous and partly indignant. The papers dealt with some aspects of the theory of gases. Those formulae had been worked out by others twenty-four years earlier. They dealt with methods of measuring the velocity of light, methods that had been in use decades before that. At first glance it seemed as if somebody with a restricted mentality had tried to gain some doubtful fame by doubtful methods. But a careful reading of the manuscripts made it clear that their author, the teacher Konstantin Eduardovitch Ziolkovsky, simply had not known that these formulae and methods existed.

One of the leading men of the Society took it upon himself to write to Ziolkovsky, to inform him about his strange misfortune, and to express the interest of the Society in his future work. The man who wrote that letter was Dimitri Mendeleeff, the famous discoverer of the periodic system of the elements.

Ziolkovsky passed over his disappointment later with the remark that it had been "good practice," but he concentrated on inventions from then on. He also became interested in airships and he came to the same conclusion as Ganswindt—Ganswindt would have sued him if he had known—that airships were too small to work well. He began to work on a large all-metal ship.

But there was something that was not known: how much skin friction would a metallic ship create at a certain speed? Ziolkovsky

thought about the problem, but it could be decided only by experiments with models. For these experiments he built a small wind tunnel in 1891, possibly not the first in the world but certainly the first in Russia. Mendeleeff was interested in Ziolkovsky's airship plans and helped as much as he could. It was probably mainly his influence that made the Academy of Science in St. Petersburg contribute 470 roubles to Ziolkovsky's work. Ziolkovsky also had a friendly press, and newspaper readers from various parts of the country contributed small amounts, all in all 55 roubles. Ziolkovsky was perfectly aware of the fact that they were meant as alms. But he did not return them in indignation as most people of his period would have done; he used the money for his research work.

One night in Moscow, when he was still a boy, he had looked up to the sky and tried to visualize what he had learned: the spinning earth in space, racing around the sun along its orbit. Spinning suggested centrifugal force with the familiar picture of a weight whirled around on a piece of string. Such strings occasionally snap—and young Ziolkovsky found no more sleep during that night. He was, as Columbus' son said about his father—although in another sense—"drunk with the stars." The idea of space travel had caught him and never let go again.

In 1895, many years later, Ziolkovsky dared to mention space travel cautiously in an article for the first time. To his surprise the article was printed (in *Nature and Man*) and from then on the idea of space travel crowded everything else from his mind. After that first publication, he really began to think about the problem, or rather the complex of problems, taking them up one by one.

Between the planets there was mostly empty space, hence the space vessel would have to have a completely sealed cabin with oxygen reserves and air purification. Because of that empty space only a mode of propulsion which would work in empty space could be considered: that was the principle of recoil, the rocket. But rockets were not efficient enough, they needed higher efficiency. Higher efficiency could be obtained best by using fuels with a higher exhaust speed. Hence Ziolkovsky decided on liquid fuels of the gasoline type for the spaceship. He went over the whole problem step by step and in 1898 he had something that could be called a preliminary study. He submitted it to the editors of a journal called *Science Survey* (*Na-ootchnoye Obozreniye*) and the

editors, apparently after hesitating for quite a while, finally published it in 1903.

Nobody paid much attention to it. Outside of Russia it remained unknown because of the language in which it was written and inside of Russia those who may have felt intrigued by Ziolkovsky's reasoning probably waited for comments from other scientists, comments which were not forthcoming. But Ziolkovsky had now found his field. He did get some encouragement from readers and he also saw that his airship plans were crowded into virtual oblivion by the large-scale experiments of Count Zeppelin upon whom all attention began to center.

Consequently Ziolkovsky devoted all his energies and probably all his spare time to the problem where such competition did not exist. A series of articles appeared during the years from 1911 to 1913 in a technical magazine with the title *Aviation Reports*. This was a magazine that was widely read in Imperial Russia (it folded with the revolution) and it brought Ziolkovsky a disciple who proved very valuable, a writer on scientific subjects, mainly physics, by the name of Dr. Jakov I. Perelman. Perelman, who was later to become the science editor of the *Krassnaya Gazyeta* in Leningrad, devoted several chapters in his *Entertaining Physics* books to Ziolkovsky and to rockets in general. But he also wrote a straight popularization of Ziolkovsky's more severe works, and it was Perelman's eloquence which made Ziolkovsky's name known to the Russians.

There are many legends connected with that early period which unfortunately acquired some permanence because a German-writing Russian by the name of Aleksander Borissovitch Shershevsky uncritically put hearsay into some of his articles and into his one and only book. One of the legends is that Ziolkovsky and the Frenchman Robert Esnault-Pelterie (one of the French pioneer aviators who later became an ardent devotee of space travel problems) held a debate on space travel in the presence of the Czar. Determined to set the record straight, I asked both of them by mail about this assertion. Robert Esnault-Pelterie wrote at once saying that the legend may have originated with the fact that he, a year or two before the First World War, had delivered a lecture at St. Petersburg. But the Czar had not been there. Nor had he ever seen him. Nor had he ever met *le Monsieur Ziolkovsky*. And his lecture had been *pas sur l'astronautique mais sur l'aviation*.

Ziolkovsky's letter, written in longhand and in German, arrived a week or two later. The story simply wasn't true.

Another legend, originating from the same source, stated that the well-known Russian astronomer Tikhov had devoted much of his time to problems of space travel. Perelman assured me that all that Tikhov had ever done along that line had been to be chairman during one of Perelman's lectures.

The First World War, naturally, put a stop to Ziolkovsky's and Perelman's endeavors. But the Russian revolution did not touch them; in fact the Soviet government, before it was completely stabilized, put a protecting hand over Ziolkovsky's head. He mentioned in a letter to me that he received sums of money "quite frequently," probably by way of honorariums for reprints of his former articles which were published in the form of pamphlets by the Kaluga Branch of the Government Publishing Office. The first publication by Ziolkovsky under the new regime was not a straight scientific work, however. It was a novel with the title *Outside of the Earth*, a fictionalized account of a journey away from the earth. Such books always sold well in Russia and the commissar in charge may well have thought that Ziolkovsky's novel was just one more of that type, even though he was probably informed that every sentence was the result of painstaking research.

My reason for assuming this is the fact that none of Ziolkovsky's "straight" works was reprinted until after the year 1923 when the German-writing professor Hermann Oberth published a work on the theoretical possibility of space travel in Munich. One year later the Government Publishing Office in Kaluga reprinted the long article that had originally appeared in *Na-ootchnoye Obozreniye* in 1903. The title was changed for republication and now read: "*Rakyeta v kosmeetcheskoye prostranstvo*" ("The Rocket into Cosmic Space"). The title page of the octavo pamphlet of thirty-two pages was bilingual, a German translation of the title ("*Eine Rakete in den kosmischen Raum*") being at the head of the title page. It also carried a preface in German by Aleksander L. Tchijevsky, stating that the Russians, after a short review of Oberth's book had been printed in the official Russian dailies, remembered that their compatriot Ziolskovsky had expounded the same theory thirty years earlier. The whole preface, while written in German, was actually an emphatic appeal for patriotism, closing with the words: "Do we always have to get from foreigners what originated in

our boundless homeland and died in loneliness from neglect?"

The other articles appeared in quick succession after that; Ziolkovsky found himself honored beyond his most ambitious expectations and when he rounded his seventy-fifth year in 1932, official agencies prepared articles about him which were published in all the official newspapers. The *Osoaviakhim*, the Russian aviation organization, prepared a large-scale celebration of his birthday.

He died four years later, in 1936.

Another name was to be added to the list of honored pioneers, the name of the late Dr. Robert Hutchins Goddard, of Worcester, Mass.

Dr. Robert H. Goddard, whose name flashed into prominence in 1919 with the publication of a 69-page pamphlet called *A Method of Reaching Extreme Altitudes*, was and remained all through his life the "mystery man" of rocket research. Whenever his name fell during a discussion among interested people one could be sure to see two parties form at a moment's notice, one full of fervent and not always justified admiration, the other bitterly denouncing Goddard for his secretiveness, which easily created wrong impressions.

The known facts about Goddard, his life as well as his work, are few and sketchy. *Who's Who* at least provides an outline of his life by stating:

Born Worcester, Mass. Oct. 5, 1882, son of Nahum Danford and Fannie Louise (Hoyt) Goddard; B. Sc. Worcester Polytechnic Institute, 1908; M. A. Clark University, 1910; Ph.D. Clark University 1911. Married Esther Christine Kisk, June 21st, 1924, Instructor in physics, Worcester Polytechnic Inst. 1909-11; student at Princeton Univ. 1912 and 1913; at Clark University, instructor and honorary fellow in physics, 1914-15; assistant professor, 1915-19, professor since 1919; also director of Physical Laboratories. . . .

All this implies an ordinary academic career—but it was interrupted by a Navy commission during the First World War, a Navy commission which was to make Dr. Goddard one of the men whose names will never be forgotten.

It seems that he had been interested in rockets and rocket motion; consequently one of his assignments was the improvement of Navy signal rockets. Dr. Goddard produced such an improvement

quickly and then became the world's foremost rocket expert for his time.

He conducted a series of tests with metallic nozzles and various kinds of commercial smokeless powders and began a mathematical investigation of the various factors determining rocket motion. The result of this work was the Smithsonian Report mentioned. It was a good technical report, condensed and terse, and not at all meant for the general public—but it achieved enormous publicity. The report, more or less by way of example, discussed the possibility of a rocket reaching the moon and exploding a load of flash powder there to mark its arrival.

This would have been an interesting story if it had originated with anybody. But this time it did not come from the proverbial garret of a poor and presumably half-mad inventor. It came from a man who was a Doctor of Philosophy and a professor of physics who had had technical Navy assignments and whose work had been published by an organization of such standing as the Smithsonian Institution. A moon rocket, no matter how hypothetical, originating from such a source was not just somebody's dream, it was Science with a capital S.

Goddard was on the verge of becoming a great popular figure, of attaining, at least in popular estimation, something like the rank of an Einstein. But then Goddard chose to play hide and seek with his would-be admirers. What may have been natural reticence developed into almost maniac tight-lippedness, for which he apologized on one occasion, by saying that all his ideas had been copied, without credit to him, in Europe.

The real facts were that nobody in Europe (or in America, for that matter) knew what he was doing; the letters written to him brought only courteous and short (and sometimes curt and short) replies which did not contain a shred of information. Even now the description of his work has to be taken from his second Smithsonian Report of 1936 which is as short as it is evasive.

While nobody in Europe was in a position or even had a desire to copy Goddard's work, the professional air over Europe was full of wild rumors about it. Goddard failed to display what is known as "scientific courtesy." Since it seemed unthinkable that he should do that without pressure from somebody, and since it was known that he had once worked with American military authorities, the explanation seemed simple: Goddard had been pledged, it was

assumed, to military secrecy and therefore could not speak about his work. Europeans, being what they are, thought that Goddard would be shot if he answered questions, and felt at liberty to speculate about the marvelous things he must have accomplished in the meantime.

Russian books did not hesitate to publish drawings (of the type of Fig. 20) of "Goddard's 300-mile rocket torpedoes" and in Germany people sincerely believed it when they wrote: "Goddard's



20. Professor Goddard's Alleged 300-Mile Air Torpedo. During the twenties both Russian and German magazines published this picture as a drawing of "American 300-mile long-distance rockets, invented by R. H. Goddard."

cooperation with the U. S. War Department is an open secret" (Valier's *Raketenfahrt*) and Goddard "has succeeded in shooting rocket-propelled aerial torpedoes to a height of 100 miles" (Sher-shevsky's *Die Rakete für Fahrt und Flug*).

Nothing of the sort was true. Goddard was actually working with (comparatively small) grants first from Clark University and then from the Guggenheim Foundation and from the Smithsonian Institution.

During the period from 1920 to 1922 Goddard worked in his spare time with grants from Clark University, testing liquid fuels of various kinds. Like Oberth he came to the conclusion that oxygen and hydrogen were the most powerful but that "it seems likely that liquid oxygen and liquid methane would afford the greatest heat value of the combinations which could be used without considerable difficulty. The most practical combination, however, appears to be liquid oxygen and gasoline."²

² This statement, as well as all others in quotation marks, is taken from the second Smithsonian Report, *Liquid-Propellant Rocket Development*.

"On November 1, 1923, a rocket motor operated in the testing frame, using liquid oxygen and gasoline, both supplied by pumps on the rocket."

"The first flight of a liquid oxygen-gasoline rocket was obtained on March 16, 1926, in Auburn, Mass., and was reported to the Smithsonian Institution May 5, 1926."^{*}

"The rocket travelled a distance of 184 feet in 2.5 seconds, as timed by stop watch, making the speed along the trajectory about 60 miles per hour. Other short flights of liquid oxygen-gasoline rockets were made in Auburn, that of July 17, 1929, happening to attract public attention owing to a report from someone who witnessed the flight from a distance and mistook the rocket for a flaming airplane."

This was the experiment which was reported all over the world as "explosion of a Goddard rocket." Prof. Goddard, in his second report, stated that this rocket, which was of the tail drive kind, carried a "small barometer and a camera, both of which were retrieved intact after the flight."

Some more tests were made in 1929-1930 at Fort Devens, Mass., "on a location which was kindly placed at the disposal of the writer [Goddard] by the War Department." This fact, no doubt, accounted for all the wild stories making their rounds through the papers, but I should think that Professor Goddard would have been given the opportunity to deny them, if he had so desired.

These experiments were beset with one main difficulty, the transportation conditions in winter. But this was remedied by a grant from the late Daniel Guggenheim (augmented by a grant from the Carnegie Institution) which permitted Goddard to set up a laboratory in ideal climate, in New Mexico. The Mescalero Ranch near Roswell was chosen.

"A shop 30 by 55 feet was erected in September 1930 and the 60-foot tower previously used in Auburn and Fort Devens was erected about 15 miles away. A second tower, 20 feet high, was built near the shop for static tests, that is, those in which the rocket was prevented from rising by heavy weights, so that the lift and general performance could be studied."

"The first flight obtained during this period was on December 30, 1930, with a rocket 11 feet long, weighing 33.5 pounds. The

^{*} Professor Goddard refused permission to reproduce his photograph of his first rocket.

height obtained was 2,000 feet and the maximum speed was about 500 m.p.h."

"A beginning of the problem of automatically stabilized vertical flight was also made and the first flight with gyroscopically controlled vanes was obtained on April 19, 1932 . . . the method of stabilization consisted in forcing vanes into the blast of the rocket (U.S. Patent, *Mechanism for Directing Flight*, No. 1,879,187, September 27, 1932) by means of gas pressure, this pressure being controlled by a small gyroscope."

This series of experiments was then discontinued in May 1932 "owing to the economic conditions then existing." In October 1934 a new Guggenheim grant permitted him to continue the work in New Mexico. It seems that the main objective of the experimental research from that date on was not the rocket motor but the stabilizing mechanism.

A pendulum stabilizer was used first, but it would function only at the beginning of an ascent, since a pendulum would tend to point in the direction of the greatest acceleration. When the acceleration is high it will simply respond to that acceleration which is not at all what it is supposed to do. Goddard had expected this performance and knew that he would have to use a gyroscope for this purpose. The first test with gyroscope stabilizer was made on March 28, 1935. "The greatest height in this flight was 4800 feet, the horizontal distance 13,000 feet and the maximum speed 550 m.p.h."

What seem to have been the last two experiments of that series of tests attracted much public attention. Professor Goddard reported about these tests at a meeting of a scientific society held between Christmas and New Year's Eve, 1935. The newspapers carried the report of the meeting on New Year's Day, 1936, and were even more excited about it than they usually are on such an occasion. In their excitement some of them forgot to mention that Professor Goddard did not have the whole gathering of scientists out there in the desert near Roswell, but that he showed films taken during the tests. From this misunderstanding it was generally concluded that the rocket ascents had just been made; actually they took place on May 31, 1935 (ceiling 7500 feet) and on October 14, 1935 (ceiling 4000 feet).

In the films the work of the stabilizer could clearly be seen, "the first few hundred feet of the flight reminded one of a fish

swimming in a vertical direction," to use Goddard's own words. While the stabilizers worked satisfactorily the performance of the rocket motors was evidently poor. The rockets left a conspicuous smoke trail and there were even occasional flashes below the nozzle, the result of the explosions of gasoline vapor in the air. The weight of these rockets, the report states, "varied from 58 to 85 pounds" but the meaning is not quite clear. It may mean that the fueled rocket weighed 85 pounds and the empty rocket 58 pounds. It may also mean that one rocket weighed 58 pounds and the other 85, or, finally, that in one test it was fueled to a gross weight of 58 pounds and in the other to a gross weight of 85 pounds.

Between this report and the outbreak of the Second World War there is, as usual, silence. Nothing was heard of Goddard save for a list of patents.⁴ After Pearl Harbor it became known that Goddard had resumed work for the Navy, being occupied, it seems, mainly with devices for rocket-assisted take-off for airplanes.

In August 1945, the daily press suddenly carried notices of his death. On August 10, 1945, he had succumbed after a throat operation. His name will always be remembered, but it would be much better if he had left more than two short reports and a score of patents to perpetuate that memory.

⁴ See list of patents in the "Notes."

Chapter 5:

THE BATTLE OF THE FORMULAE

To believe that everything has been discovered is just as profound an error as it would be to accept the horizon as the world's boundary.—Lemierre.

BY THE end of 1913 a noticeable amount of printed matter about rocket propulsion had accumulated in the dozen really large libraries in the world. But although the total amount was comparatively large, it would have been hard to find. There were, of course, some twenty books and pamphlets on the old war rockets, mostly in English, French, and German. The remainder consisted, aside from a few privately printed pamphlets, of articles in French and Russian aviation magazines and, except for those by Ziolkovsky, all these articles dealt with a side issue: the application of rocket propulsion to airplanes.

By the middle of 1914 the First World War broke out and all active thought stopped. By the end of 1918 everything that had once been planned was forgotten.

In the year following the end of the war, 1919, a few copies of Robert H. Goddard's *Method of Reaching Extreme Altitudes* found their way across the ocean and ended up on the shelves of European libraries. But the value, and even the contents, of this book, were not immediately noticed. It is possible that the somewhat noncommittal title created the impression that it was simply a discussion of a new technique in meteorological research work and therefore of no interest to anybody except professional meteorologists. At any rate it did not quite create the stir which it did create in America. Librarians were not even sure whether they had it, when asked, and it remained virtually unknown for a number of years.

But Europe, for some reason which is hard to evaluate, was to become the center of rocket research and of the idea of space travel for a full decade. And the Europe of 1919 still had other worries, worries of wars and civil wars, of unstable currency, and of political strife. A book published in happy America was only too likely to be overlooked.

By 1923 a good deal of the political troubles had run their course. The Russian revolution had passed through its wildest phases and the German monetary inflation had ended with suspicious suddenness. Precisely at that moment the great problem was revived.

It was done in what may be called a particularly ineffective manner. The publishing firm of R. Oldenbourg in Munich published a paper-covered pamphlet of less than a hundred pages (I learned later that its author had to pay the larger part of the printer's bill out of his own pocket) with the title *Die Rakete zu den Planetenräumen* (*The Rocket into Interplanetary Space*) by H. Oberth.¹ Nobody knew who "H. Oberth" was and the book itself did not shed any light on that question.

The introduction began with four numbered paragraphs which read as follows:

(1) The present state of science and of technological knowledge permits the building of machines that can rise beyond the limits of the atmosphere of the earth.

(2) After further development these machines will be capable of attaining such velocities that they—left undisturbed in the void of the ether space—will not fall back to earth; furthermore, they will even be able to leave the zone of terrestrial attraction.

(3) Such machines can be built in such a way that they will be able to carry men (probably without endangering their health).

(4) Under certain conditions the manufacture of such machines might be profitable. Such conditions might develop within a few decades.

In this book I wish to prove these four assertions. . . .

The rest of the book sounded exactly like those four paragraphs. The four "assertions" were subjected to a mathematical analysis that progressed step by step. A rocket ascent to realms beyond the stratosphere was dissected mathematically and turned out to be a problem in fuel consumption. That, of course, led to an investigation of the rate of fuel consumption which, in turn, depended on the velocity which brought up the problem of "optimal velocity."

¹ The pronunciation of the name is *O-bert*, with the stress on the O. Hermann Oberth was born in Hermannstadt, Transylvania, on June 25, 1894.

It is almost superfluous to mention that proof of those four assertions was established, but it was such that only mathematicians, astronomers, and engineers could read it. As far as the general, even the interested, public was concerned, the book might just as well have been printed in Sumerian characters.

There is a good reason for writing of this type. It is simply that the originator of a new thought tries to convince the professionals first, that he seeks professional criticism of his thesis. It happens every day in science and fulfills its purpose with only rare exceptions. Oberth's book, for some reason, turned out to be such an exception. It became, incredible as that may seem, a limited public success; the first edition was sold out in a short time and the orders that piled in at the publisher's office almost exhausted the second edition before it was even printed. While the small book was successful in that respect, it did not do so well in the other. It sought the professional criticism of the professionals—but, of course, there was no such profession. Many of those who should have read it carefully did not do it at first because they felt that this was something beyond their ken, that it was not really a problem in their own profession.

Since this book proved to be so important, it may be useful to give a short outline of its contents. It was divided into three parts. The first part dealt with more or less general questions of rocket motion and contained a lot of things that people—meaning physicists, etc.—should have known but didn't, for example, the statement that a rocket can surpass the velocity of its own exhaust. It emphasized the importance of the "free ascent" (without power, after the supply of fuels has been exhausted). To repeat in bulk at this point what the first part of the book said would result in a long chapter full of technicalities; it will be easier and better to explain these things one by one as we come across them later on.

The second part consisted of the description of an assumed altitude rocket called *Model B*. This description was not supposed to be taken as literally as many critics took it. It mainly had the purpose of discussing the whole problem in its applications to one particular instance. The third part—incidentally the only one that could be read without getting caught in the barbed wire of equations every two seconds—dealt with general prophecies about the probable achievements. Oberth described a theoretical spaceship,

discussed the possible objections, and developed the first sketchy theory of a station in space.

There was just enough of it "readable" to intrigue a comparatively large number of people. But the professional critics, the people for whom the book had really been written, did not do so well. Some just announced it, a few others wrote articles which were a condensation of Oberth's statements. Some, finally, criticized it, as they were expected to do. But what they said was, for the most part, surprising—in one of the more uncomplimentary shades of meaning of that word.

Two or three well-reputed astronomers, men who certainly should have known better, simply "killed" the whole idea—or so they thought—by stating that all these things are very nice and interesting but lacking in foundation since everybody knows that there can be no recoil in empty space. Another critic, physician by profession, added some more devastation. Not only was there no recoil in empty space; the idea of manned rockets was preposterous for all times to come because people, as soon as they left the atmosphere of the earth (provided it could be done), would be subjected to the gravity of the sun which is powerful enough to squash their bodies.

The good doctor had taken his figures from tables in an astronomical book. Unfortunately the figure for the sun's attraction in that table *referred to the surface of the sun itself* and not to a distant place such as the orbit of the earth or a point near that orbit.

Another critic, an aviation expert, stated in a puzzled manner that he was inclined to believe Oberth, but that he could not understand, try as he might, why the exhaust gases should follow the rocket if the latter, after some time, surpassed its own exhaust velocity. That the exhaust velocity, *seen from the rocket*, never changes, apparently did not occur to him. The whole puzzle which he could not solve was caused only by the (unconscious) mental change of viewpoint: by looking at the exhaust once from the rocket and then from the ground.

Another one, by his profession as a physicist more given to precise statements, said that the rocket, of necessity, could not surpass the velocity of its own exhaust because the efficiency would surpass 100 per cent in that case. And an efficiency of more than 100 per cent is, obviously, not possible. This was a strange mixture of cor-

rect and incorrect conclusions. It is true that the efficiency of a rocket which moves, say, twice as fast as its own exhaust velocity, seems to be far above 100 per cent, if you consider only the time interval when that condition takes place. But it is wrong to do that. The apparently impossible efficiency occurs, in a manner of speaking, at the expense of the very low efficiency at the beginning of the ascent when the rocket moves very slowly. If you look at the whole performance, the efficiency never even approaches 100 per cent, which is what should be expected in the first place.

What could happen if you went off on a tangent somewhere in the middle of the whole problem was nicely demonstrated by another mathematician and physicist who calculated with gusto that the most powerful explosive known could not even lift its own weight to a greater height than about 400 kilometers (250 miles). He forgot that the fuel is not carried along but only its energy.²

Oberth, as can be gathered from these criticisms, had merely expounded the simple theories mentioned in the chapter "Rockets": that reaction does not depend on the presence of an atmosphere; that a rocket can surpass its own exhaust speed; and that the easiest way to achieve a good performance is to attain a high velocity which, in turn, implies the use of a fuel with high exhaust velocity. This theoretical reason alone is sufficient to decide in favor of liquid fuels (mechanical considerations all point in the same direction) the most ordinary of which, gasoline, has more than twice the exhaust velocity of ordinary rocket powder.

Oberth did not know about Ziolkovsky's then forgotten articles in which the Russian schoolteacher had come to the same conclusions. It would not have helped him even if he had received a complete file of these old aviation magazines, because he could not

² Dr. Otto Steinitz, who later worked with Oberth on some patents, nicely explained this mistake by the use of an analogy. When shooting an arrow muscular energy is stored in the wood of the bow. It amounts to about 20 kilogram/meters for every kilogram the bow weighs. Twenty kilogram/meters would be just enough to lift the bow 20 meters or about 66 feet and the conclusion would be that an arrow cannot be shot higher than 66 feet, no matter how large the bow, since you cannot store more than 20 kilogram/meters of energy per kilogram of weight. But you don't shoot the bow, you shoot the much lighter arrow, weighing, say, one tenth of the weight of the bow. Consequently it can rise ten times as high as the bow could lift itself. In the case of a rocket, the rocket itself represents the arrow and the fuel the bow, and the altitude is not limited by the weight (mass) of the exhaust gases—the product of the fuel—since these are left behind.

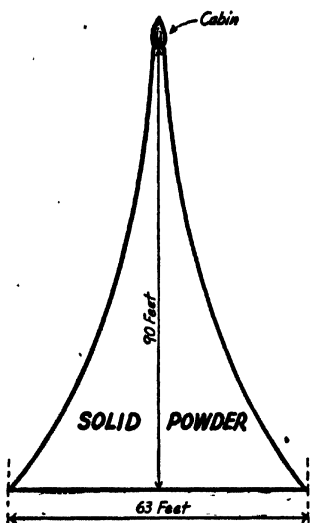
read a single word of Russian. Nor did Oberth, or anybody else, know that Professor Goddard was actually experimenting with liquid fuels at that time, under enormous and unnecessary secrecy which has become a standard joke in interested circles.

But Oberth's book did more than confuse the critics. It encouraged others who had similar ideas to appear with them before a surprised public. One of the most important publications, following close on the heels of Oberth's book, was another tall thin volume of similar external appearance and written in a similar manner. As a matter of fact, it looked so forbidding to prospective buyers who leafed through it in the bookstores that the first edition of only fifteen hundred copies was never completely sold.

Its author was Dr. Walter Hohmann, city architect of the City of Essen-on-the-Ruhr, and the title was *Die Erreichbarkeit der Himmelskörper* (*The Attainability of the Celestial Bodies*). The title does not sound quite as clumsy in German as it does in English, but it is severe enough. As for the table of contents, it read: "I. Departure from the Earth; II. Return to Earth; III. Free Coasting in Space; IV. Circular Orbits Around Other Celestial Bodies; V. Landing on Other Celestial Bodies."

If that sounded intriguing, a reader was subjected to a cold plunge when he opened the book, say, at Chapter 2 and began to read: "In order to reduce the velocity of a vehicle of the type described in the preceding chapter from v_1 to zero, if that vehicle is falling toward the earth from a very great distance, we require the same time of operation t_1 as calculated by means of equation (10) but the stream of the exhaust dm/dt has to point in the direction of the movement." The whole book read like that and years later the editor of a large newspaper came to my office, pulled a copy of Hohmann's book from his brief case and said: "I want to write a feature article about you people and you, Mr. Ley, have written that Hohmann's contribution is important. All right, I believe you and I want to say something nice about him . . . *but what does it all mean?*"

I can understand why Hohmann's book was even more obscure to people like that newspaper editor than Oberth's book. Oberth, at least, had spoken about a rocket called Model B and about another one called Model E. He had calculated their performance and stated what they ought to be able to do. To the engineer these models B and E were only examples, sketches supplied for the

21. *The So-Called Hohmann Spaceship.*

purpose of making a definite calculation. To the layman—and that was practically everybody except engineers and, possibly, astronomers—the models B and E were not examples but projects, something that could somehow, even though with difficulties, be visualized.

Hohmann, as he wrote me later, had thought about actual constructions but had not come to a presentable conclusion. Consequently, he had restricted himself to a mathematical investigation of the quantities of a given or assumed fuel which would be required for an assumed operation. It was all highly interesting and of great scientific value, but it read very much like a prescription.

Just for the purposes of illustration Hohmann had drawn a powder tower (Fig. 21) which, of course, made no sense unless explained. It is by no means a "design," as some people thought; it is one more of these abstract examples. If you imagine that this powder tower burned at the base only and needed eight minutes to be consumed completely, you could draw eight parallel lines through it. You would then get eight disks of powder, of equal thickness but of different diameter. Also of different weight, of course. These eight slices, or rather the mass of these eight slices, illustrated the amount of fuel required per minute. The biggest slice at the bottom was the amount for the first minute of operation and so on. You could also subdivide it into seconds of operation and find the amount required from second to second.

After these two books there was clearly need for some understandable writing. If the whole thing was to be of any value the matter must not rest with theoretical findings. Something had to be built or Oberth and Hohmann would be merely repetitions of Ziolkovsky, possibly to be revived again another twenty years later in another repetition of the same thing. The idea had to leave the

study to enter the laboratory and later the workshop. But people who could unlock laboratory doors had to be interested first, and that required non-technical language not only for those who could not understand the technical language, but also for those who could, but did not know of the existence of these formal treatises or who needed an interest-rouser.

It was reasoning of this kind which prompted a man by the name of Max Valier, known as a popular writer on scientific subjects, to approach Oberth with the proposal of emulating Dr. Perelman. Of course he did not put it that way, since neither of them knew either of Ziolkovsky or of Perelman, but the idea was the same.

Oberth accepted the proposal. He had had the idea of a popular book himself, as he told me later, but he was overburdened with work. His own studies for a teaching job were not quite completed. He worked on extensions of his own rocket theory and he also spent quite some time in discussions with financiers and in working out simple demonstrations for them.

The discussions about financial support came to nothing.

The financier or financiers had apparently held the customary conception of professors who invent things, the conception you can find in print in innumerable stories.

They had expected an old or at least elderly man who had labored over one idea all his life and who carried battered manuscripts around with him, manuscripts wrapped up in newspapers and tied around by strings with many knots in them. They probably had had secret hopes concerning complete models which would fly around in the conference room. They had quite definitely expected that the investments they were—perhaps—going to make would bear fruit in not more than two years.

Then they saw that the professor was a slender man who looked taller than he was because of his gangling build, a young man who had just rounded the third decade of his life. The long matted hair and big beard they had visualized turned out to be a short crop of black hair and a small moustache. The only thing that was "professorial" about him was his manner of speaking—whenever Oberth opened his mouth you got the feeling that you were in a classroom and there was no way of leaving, not even on that famous urgent errand, until the lesson was over.

They learned that Oberth had not kept any great secrets to himself, as they had expected, but that everything could be found in

his book (which they couldn't read), that the program of carrying out what Oberth had visualized was a program of decades and not of years. They learned that the demonstration models were rigged up at home and were not even patented! Like many people they did not know what a patent was, but they labored under the belief that a patent is an expression of official approval of an invention. Actually it only certifies that the idea was new on the day it was submitted, carrying with it a license to sue imitators.

After having wasted a good deal of time and effort, Oberth returned to the country of his birth, Transylvania, an old German-speaking colony of German Saxons wedged in between Hungarian and Rumanian territories and politically belonging, at that time, to Rumania. More specifically Oberth went to Schässburg in January 1925, leaving it in February to take a post as professor of mathematics at the High School of Mediash, also in Transylvania.

By that time Max Valier's book was about ready and it appeared soon afterward. But it failed to be what the author had promised. It was full of well-meant but ridiculous illustrations. When it came to difficult points, Valier resorted to flippancy which he took to be humor. A great deal of the book was in fine print ("to be skipped by the lay reader") full of calculations, most of them made by Oberth. In spite of all these faults it sold at a fair and steady rate, a reprint became necessary roughly once a year, and some of the most glaring faults were remedied in these reprints. Some others were added later by Valier in an effort to display independent thinking.

As a matter of fact it was the poor quality of Valier's book which made me enter into competition with him although I was not quite twenty years old at that time. With the enthusiasm peculiar to that age I decided that I could do better than Valier. I sat down and wrote a small and formula-free book on the same subject. It was printed in 1926 and sold some six thousand copies during the following six years. To my surprise many people, including Oberth, said that it was actually better than Valier's—at any event it did what Valier had failed to do, it told the whole story understandably and in as few words as possible.

It was then that the problem began to assume international dimensions. In Russia, as has been told in the preceding chapter, Ziolkovsky's old articles were reprinted, along with new editions of Dr. Perelman's book. In Moscow even a student society was

formed with the purpose of advancing the problem of space travel. It was short-lived which was just as well since it had not been too serious to begin with. It was not until November 1929 that a serious student society was founded in Russia, with one group in Moscow and another in Leningrad, the latter under the experienced leadership of Professor Rynin and Dr. Perelman.

The same Professor Rynin had then just begun to publish the first parts of his enormous nine-volume work *Interplanetary Travel*. And in France one of the French pioneer aviators, Robert Esnault-Pelterie, delivered a lecture on the problems of space travel, addressing the *Société Astronomique*, created originally by Camille Flammarion. The lecture was published in 1928 in book form. The date of the lecture had been the 8th of June 1927—precisely three days after several gentlemen, living in and near the comparatively small provincial town of Breslau in Germany, had met in the back room of a restaurant to found a society for the purpose of spreading the thought that the planets were within reach of humanity if humanity was only willing to struggle a bit for that goal.

The name of that society was *Verein für Raumschiffahrt* (Society for Space Travel). But people later referred to it as the *VfR*, while the common appellation in English-speaking countries became The German Rocket Society.

If I remember correctly, German law provided that the minimum number of people who can legally found a society is seven; I don't think the assembly exceeded that number by more than two. One of those present at the meeting, a man by the name of Johannes Winkler, agreed to accept the presidency of the society—Valier had refused because of his almost continuous lecture tours—and to publish a small monthly magazine which was to be the mouthpiece of the society. This monthly magazine, called *Die Rakete* (*The Rocket*), was actually published immediately afterward and appeared regularly until December 1929. Winkler invited Oberth and Hohmann to join and they did. Winkler also undertook the task of registering the society with the courts in Breslau. This was required for business reasons: only a society registered with a court of law existed legally and that fact was indicated by adding the letters *e.V.* (*eingetragener Verein* or "registered society," implying about the same as "Inc."). There was a little trouble with this particular incorporation; the court found that the word *Raumschiffahrt* (space travel) was not defined in any dictionary and that the public,

therefore, would not be able to judge the purpose of the society. A change of name was suggested. However, the court finally relented and, since new inventions require new words, it accepted the registration of the society under the condition that the document of registration itself define the name in an unmistakable manner.

The growth of the VfR was rapid. Within a year it acquired almost five hundred members, among them everybody who had ever written about the problem in Germany and in neighboring countries. Oberth and Hohmann, Dr. von Hoefft and Guido von Pirquet in Vienna, Professor Rynin and Robert Esnault-Pelterie—all had joined. The program was, in outline, to interest as many people as possible, to collect membership dues and extra contributions, and to create a fund for experimental work. And since existing literature in the field was already obsolescent to a certain extent, I began to plan another book, to be written in collaboration by all the leading men of the society. My publisher promised to publish it and to advertise the VfR in the process, and the VfR, in turn, promised to advertise the book. It appeared under the title *Die Möglichkeit der Weltraumfahrt* (*The Possibility of Space Travel*) in the spring of 1928.

But meanwhile several other developments had taken place, some of them good, others less so. One of the more important ones was a series of articles attacking Oberth in a rather vehement manner. They were published in the very important journal of the VDI (*Verein deutscher Ingenieure*, Society of German Engineers) and they were signed by Privy Councilor Professor Dr. Lorenz of Danzig. Privy Councilor Lorenz did not make any elementary mistakes; he simply proved that Oberth's spaceship could not acquire the famous velocity of escape of about 7 miles per second. His arguments and calculations boiled down to the statement that a rocket fueled by known fuels, if it were to acquire the necessary escape velocity, would have to weigh thirty-four times as much when fueled as it weighed when empty. The conclusion drawn from these calculations read: therefore it cannot be done.

Oberth, naturally, wrote a reply. It was rejected. Dr. Hohmann, being a member of the VDI as well as the VfR, also wrote a reply. It was rejected. The excuse given was lack of space. The real reason, which I learned through a personal conversation years later, was: "We cannot permit people half his age to contradict the Privy Councilor!"

But another society, the WGL (*Wissenschaftliche Gesellschaft für Luftschiffahrt*, Scientific Society for Aeronautics) was not so narrow-minded. That society held annual meetings and the meeting for the year 1928 had been scheduled to be held in Zoppot near Danzig. The WGL invited Lorenz to attack Oberth and it invited Oberth to defend himself. Lorenz spoke at length; Oberth answered with a very short speech. He pointed out that he had followed the Privy Councilor's arguments and that one could arrive at the ratio of 34 to 1. Personally, by knowing that one factor was more advantageous than the Privy Councilor had assumed, he had arrived at the ratio of 20 to 1, as the Privy Councilor would have seen if he had finished reading Oberth's book. But in any case Oberth could not help it if the Privy Councilor refused to believe that it is possible to build an aluminum pot into which one could pour enough water so that the full pot would weigh twenty times as much as the empty pot.

I may add that Lorenz never wrote about rockets again.

After the meeting, Oberth, Mrs. Oberth, and I sat together and complained bitterly about fate. The big book, the *Möglichkeit*, had been published just in time for the meeting in Zoppot. But something else had happened too. The headlines of every newspaper in Europe told about "the successful trial run of the world's first rocket-propelled vehicle." They referred, of course, to Opel's rocket car which had just been demonstrated to the public in a big, carefully staged show. And that was, to put it mildly, exasperating. These rocket cars and the stories around them embodied the greatest possible misunderstanding and stupidity.

The instigator of all this colossal nonsense had been Max Valier.

For some time Valier had hinted in various articles and lectures that great developments could be expected in the very near future. In January 1928 we had learned just what this great development was going to be—it was such that I had sent the manuscript of the *Möglichkeit* to my publisher without waiting for the chapter Valier had promised to contribute to it.

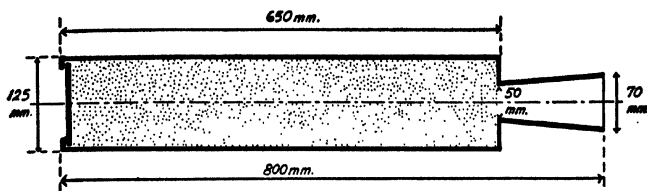
Max Valier, as he put it himself, had "succeeded in interesting Fritz von Opel in rockets." This, of course, was a very euphemistic way of putting things. It was one of those statements that are correct and truthful as far as the wording goes, but which are, in fact, untruthful because they lack the implications that may reasonably be expected.

The fact was that Max Valier had one day had an opportunity to see Fritz von Opel who was the owner of a large factory manufacturing cheap cars. Although he always denied it, nothing flattered Opel so much as hearing people refer to him as the German Henry Ford. When listening to whatever it was Valier told him, Fritz von Opel had a brilliant idea. He saw an opportunity of purchasing unlimited amounts of publicity with what was for him small change. He and Valier were to build a rocket automobile. How long would it take to develop a rocket motor? Valier assured him that there was no need to wait for anything; such experiments would be just as valuable from the scientific point of view if they were made with large powder rockets, and large powder rockets could be purchased on short notice. Of course the experiments had no value either way, but Opel did not probe that question. That was not what he was interested in. Being a shrewd businessman, he answered reluctantly that he might consider it if Valier knew where to get the powder rockets.

Valier did—there was a factory making powder rockets in Wesermünde near Bremen, owned and run by an engineer by the name of Friedrich Wilhelm Sander. Sander did not manufacture ordinary fireworks rockets for amusement; he specialized in practical types. He made line-throwing rockets for the coastal rescue societies, signal rockets for the merchant marine and the German naval units, and other pyrotechnic devices connected with navigation. Sander's rockets were acclaimed in seafaring circles for their good performance and that good performance was due to a special process of manufacture which Sander had developed. By means of this process Sander was able to compress the powder mixture to a much higher degree than "possible"—which is to say "customary"—and since he succeeded in doing that without blowing up both the machinery and the laboratory, it was quite a feat.

Valier and Sander, when talking about the proposed use of the rockets, decided to employ "mixed batteries," consisting of both bored and solid rockets. The largest bored rockets delivered a thrust of close to 400 pounds for not quite three seconds while specially made large solid *branders*, as they were called, delivered a thrust of about 45 pounds for thirty seconds. The rockets were to be used to give the initial impulse and accelerate the car to a fair speed; the *branders* were to maintain that speed. (Fig. 22.)

Valier wanted to make a private test at Wesermünde before



22. Cross-Section of Steel-Cased, Solid Powder Sander Rocket.
125 mm. is not quite 5 inches; 650 mm. is not quite 26 inches.

going to Fritz von Opel's race track at Rüsselsheim. But Sander refused to lend his car for the experiment and Valier did not own a car. Their arguments resulted in a draw and they compromised by going to Rüsselsheim without a preliminary test. The rockets were shipped by truck—the railroad refused to transport them—and the first secret test was made on March 15, 1928. It consisted in attaching one bored rocket and one solid *brander* to a small Opel car. Opel's test driver Kurt Volckhart took the wheel, released the brakes, and ignited the rockets. The car moved very slowly and came to a stop after about half a minute—450 feet in 35 seconds!

Both Volckhart and Opel were greatly disappointed and Opel wanted to give up then and there. Sander felt insulted because Opel had said that the rockets "obviously did not work" and took one of his bored rockets, tied a long pole to it, and set it off for a vertical ascent. Opel was sufficiently impressed with this demonstration to agree to another test. This time Volckhart used the motor of the car for the initial push. When the car was moving at about 30 miles per hour, he disconnected the motor and ignited the rockets simultaneously. They accelerated the car to 45 miles per hour. Opel, somewhat pacified, ordered a special car built.

The new car was not so very special; it was an ordinary racing model without an engine and with a mixed battery of Sander rockets attached to the back of the car. The first run (April 11, 1928) was made with six rockets. One of them failed to ignite, the other five propelled the car for about 2000 feet. The next run was made with eight rockets. Again one of them failed to ignite, two others exploded without doing any harm, but the car ran some 3000 feet with an average speed of 55 miles per hour.

The next test, officially called the First Test Run, was made the following day. Five of the battery of twelve rockets did not ignite,

but the speed exceeded 70 miles per hour and the newspaper reporters present wrote enthusiastic stories keyed to a patriotic note: German science and German industry had created the first rocket vehicle in the world. Opel saw that his publicity scheme had worked after all, and while his advertising department placed full-page ads in the better magazines,³ his engineering department designed a special rocket car.

It was a long streamlined car with stubby wings mounted upside down so that they would press the car against the road. After a secret test run, Fritz von Opel himself demonstrated the car—called the *Opel Rak II*—on the *Avus* Speedway near Berlin on May 23, 1928. This run was a complete success, all twenty-four rockets ignited without any trouble, none of them exploded, and the speed of the car came close to 125 miles per hour. Opel, photographed from all sides, delivered a speech over the radio, promising an even more astounding *Opel Rak III*.

This was the run that had taken place near Berlin while Oberth defended himself against Professor Lorenz in Zoppot. Small wonder that this victory did not make us very happy.

After the *VfR* had worked itself to exhaustion explaining the difference between liquid and powder fuels, after pointing out scores upon scores of times that rockets could never be efficient unless they moved at high velocities—some 800 miles per hour or higher, after all this one of the founders of the *VfR* had gone and played around with powder rockets of commercial manufacture to pave the way for the biggest publicity stunt of all history.

The efficiency of these runs had been below 1 per cent! The expense had been fantastic.

Max Valier came close to being publicly expelled from the *VfR*. It did not happen only because the procedure would have been rather tedious, requiring a lot of correspondence since by then hardly two of the members of the board of directors resided in the same city.

Of course Opel did not stop with this. He produced the promised *Opel Rak III* which was a railroad car, built along the general lines of *Opel Rak II* but with a small battery of rockets in its nose, generally referred to as brake rockets. They were to stop the car at

³ They showed a couple in evening dress sitting in an Opel car watching a display of fireworks with the following conversation: "Rockets were not important before Opel." Answer: "Neither were automobiles."

the end of its test run, being ignited automatically. The German government had granted permission to use the track from Burgwedel to Celle (near Hanover) for this experiment. That particular track had been chosen because it was perfectly straight and level. The first run was made on June 23, 1928, with a battery of ten rockets. The ignition was timed by a clockwork device, as were the brake rockets, and the car was not manned. It attained a top speed of about 180 miles per hour, the brake rockets failed to perform properly, they shot up into the air when ignited, and the car coasted for several miles.

Retrieved and towed back to the starting point, it was charged with a battery of thirty rockets—all speed records were to be broken. But the acceleration was too high, the car derailed almost immediately and was destroyed. The fate of *Opel Rak IV* was similar. One rocket of the first series exploded and a splinter short-circuited the ignition system which made all the remaining rockets go off at once. The car jumped off the tracks and was totally destroyed. *Opel Rak V* was ready to replace it, but the railroad officials had enough; they did not permit further experiments which might ruin their best track.

Some time later Fritz von Opel switched to rocket airplanes, but gave up after one fairly successful flight near Frankfort-on-the-Main on September 30, 1929.

Nor were Opel's rocket vehicles the only specimens of their kind. His former test driver, Kurt Volckhart, had made himself independent with a rocket car of his own design. Valier had found another manufacturer of powder rockets who lent his support for the construction of railroad cars that lost all four wheels under too violent acceleration. Finally Valier even built a rocket sled and a manufacturer of small airplanes tried his hand on a rocket glider.

What had started out as a kind of scientific movement was almost smothered under a series of publicity stunts. Almost, but not quite. One of the serious attempts at furthering the progress of the idea was made in Paris with the creation of the Annual Award for Astronautics, somewhat reminiscent of the old *Prix Guzman*. But unlike the Guzman Prize, this one did not involve a large fortune nor were the requirements as high as stipulated by the far too optimistic founder of that old award, Robert Esnault-Pelterie and the Paris banker André Hirsch set aside the sum of 5000 francs

each year, to be given to the author or experimenter who had done most in furthering the idea of space travel during that year.

Oberth, meanwhile, had begun to rewrite his book for a needed third edition. It was planned on a grand scale and was to consist of two volumes, but only the first, entitled *Wege zur Raumschiffahrt* (*Road to Space Travel*) appeared in Munich in 1929.⁴ It is still the most valuable theoretical work, and it won for Oberth the first "REP-Hirsch Prize" which, as a special compliment, was doubled.⁵

That was in the autumn of 1929. Oberth was in Berlin then, having arrived in the fall of 1928. But this time he had not come for personal reasons, or for a scientific debate, or for more or less vague discussions about financial support. This time he had come for a definite purpose—he had been called by Fritz Lang to serve as scientific advisor for a movie. It was the film *Frau im Mond* which ran in English-speaking countries under the title *By Rocket to the Moon* and *The Girl in the Moon*, the latter being the translation of the German title.

The manuscript for the film had been written by Thea von Harbou (then Mrs. Fritz Lang). The book credited Oberth's first publication and my second book as scientific source material.

The news that Fritz Lang was going to make a film on space travel was very good news indeed. It is almost impossible to relate what magic that name had in Germany at that time. The first showing of a Fritz Lang film was something for which there was no equivalent anywhere as a social event. The audience—it was an unwritten but rigid rule that one had to wear full evening dress, not just a dinner jacket—comprised literally everybody of importance in the realm of arts and letters, with a heavy sprinkling of high government officials. It is not an exaggeration to say that a sudden collapse of the theater building during a Fritz Lang

⁴ I mention the planned second volume only because the first contains some references to it. The second volume never was finished.

⁵ The Prize was not awarded in 1929, 1931, and 1932. In 1930 it fell to the French engineer Pierre Montagne for a paper on "Gaseous Mixtures Utilizable in the Propulsion of Rockets." Montagne received a renewal in 1933 for a similar paper, but the real prize was not awarded in that year nor in 1934 when the French engineer Louis Damblanc received a "prize of encouragement" of 2000 francs for an exhaustive treatise on the tests and performance of powder rockets. The 1936 award fell jointly to the American Rocket Society and to Alfred Africano who was then its president. The prize-winning paper was a design for a high altitude rocket. This was the last award made.

premiere would have deprived Germany of all intellectual leadership in one blow, leaving only those who for some urgent reason had been unable to attend.

A Fritz Lang film on space travel, consequently, meant a means of spreading the idea which could hardly be surpassed in intensity and effectiveness. More than that, this connection might also mean funds, sizeable funds, for experimental work on liquid fuel rockets.

I remember that I began to needle Oberth about this during our very first meeting, but it took months until Oberth got up enough courage to press the point.

In the end it was mainly Fritz Lang himself who brought the matter to pass, dragging the reluctant and sceptical business directors of the UFA Film Company along with him. He pledged a rather large sum of money for experimental work and put pressure on the management to do the same. Of course there was a business angle to the transaction too. Oberth was to get the money for experimental work, for the construction of a rocket similar to the Model B described in his book, and for the preliminary experiments that might be required. That rocket was to be finished and ready for an ascent on the day of the premiere of the film so that it could be used for publicity. The idea was to say that this actual rocket represented the first step toward the solution of the problem shown in the movie.

The scheme might have worked out as beautifully as it was conceived if the proper men had been available to do the work involved and if there had been sufficient time for it. The time interval was impossibly short, only about twelve weeks, maybe thirteen or fourteen—nobody realized then how ridiculously short that was. And Oberth, I regret to say, was not the proper man to do it. As a matter of fact, such a man did not exist at all. There was nobody at that time who had sufficient experience with liquid fuel rockets.

Never having organized such a job before, Oberth had no idea of how to go about it. He was, a point I wish to emphasize, the greatest authority on rocket propulsion at that time (he still is, in certain respects, or rather his work is still the most authoritative of all), but he was a theorist, not an engineer. He completely lacked the ability of an experienced engineer to say in advance what can be done and what probably cannot be done. Nor did he know how to instruct a mechanic or workman who would ask how this or that should be done.

On top of all that he was greatly confused by his surroundings. He had grown up in the small towns of Transylvania and he had studied in the leisurely atmosphere of Heidelberg and of Munich.

Now he was suddenly plunged into the strange atmosphere of fast-moving, efficient, flippant, and sophisticated Berlin. Not only was he a stranger in that city of four million inhabitants, but he found himself in the very spot where the apparent turmoil of a big city appears wildest. People spoke to him in a dialect which was strange and, to him, ultra-rapid. Instead of the company of un-hurried small-town intellectuals in semi-retirement, he found himself on a movie lot in the company of film stars and directors. He ate his lunch in a canteen where Russian and English and French were as common as German; the only foreign languages in which he had a slight degree of fluency were Hungarian and Rumanian. He sat next to internationally known people, he had to speak to chairmen of huge enterprises of all kinds, he was beset by newspaper columnists and magazine writers with imposing names.

That would have been bearable, but what mainly confused him were habits which he could not understand. He was used to his bicycle and simply could not see why he had to use the subway or a taxi instead. He missed appointments because of his afternoon nap, told the truth about it, and was laughed at. Once he refused to meet a busy man who would not be free before midnight. Oberth simply answered that he went to bed at eleven. When I remarked that "busy people in Berlin sleep when they get around to it," he angrily declared that that was the wrong attitude, wrong from the medical point of view.

He was generally angry with me because I tried to advise him. He would have nothing to do with "the behavior of these soulless, money-making, German-speaking Americans who call themselves Berliners."

While he deliberately failed to conform to "habits and attitudes alien to the German soul,"⁶ he did realize that he was no engineer and that he needed an assistant who was one. He could

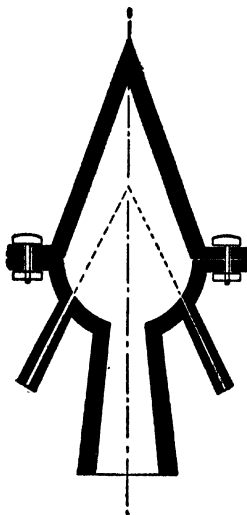
⁶ This mystic inclination naturally transformed Oberth into a Nazi in due course. In 1934 he joined the Transylvanian Nazi organization although he was, in his capacity as a high-school teacher, a Rumanian government official. I have it in writing from his own hand that he denounced me to his Nazi superior, stressing the fact that I was in correspondence with Ziolkovsky, Rynin, and Dr. Perelman.

have phoned any one of a dozen specialized employment agencies, he could have asked any one of innumerable people he had met for an able assistant. There were many unemployed and there were many able men among them, and almost anybody knew somebody else who needed a job. But Oberth put an ad into the classified section of one or several newspapers—he had come to the point where he would show people that he did not need their advice. The ad brought a number of applicants, several capable men among them, no doubt.

One of them was a small man with a strangely accented voice and a hard face, meticulously dressed and with precise military posture. He had introduced himself: "Name is Rudolf Nebel, engineer with diploma, member of oldest Bavarian student corps, World War combat pilot with rank of lieutenant and eleven enemy planes to my credit." And Oberth, who always stated his opposition to "Prussian militarism," hired Rudolf Nebel at once!

He did not make certain whether Nebel had the qualifications he needed so desperately, whether he knew the town and its smaller and larger industrial establishments well, whether he had practice in working with aluminum and magnesium alloys or at least with liquefied gases. Nebel himself told me later, without regarding it as a personal secret, that he had been graduated in a hurry during the war because he had volunteered for the air arm, and that after the war he had never worked as a designing engineer but for some time as a salesman of mechanical kitchen gadgets instead. Since jobs were almost impossible to find, all this was probably not his fault—but he certainly was not the man Oberth needed.

Thus Nebel became Oberth's first assistant. The name of the second assistant was Alexander Borissovitch Shershevsky, a Russian aviation student. Oberth had come across his name because it had appeared as a by-line under several articles in aviation magazines, articles which had found Oberth's approval. Via the editor of one magazine, Oberth had contacted Shershevsky who was simply destitute at the time. Shershevsky had been sent to Germany to study gliders, but had overstayed his *kommandirovka* and dared not go home again. Lazy by nature (and very proud of it), he earned just enough money for room and board by writing for professional journals. He could have done better if he had written about Russia but he didn't; he felt that what could be said

23. *Oberth's Kegeldüse.*

at that time would not be considered too favorable by the Western mind and he was genuinely in favor of the Soviet government. He was a refugee by accident.

The trio, consisting of a more than slightly bewildered theorist, a professed militarist, and a Bolshevist accidentally in disgrace, worked together or tried to. Shershevsky was not too eager to work, Nebel was eager and waited for orders, and Oberth was not quite certain where he should start.

He did not build a rocket to be used at a certain date—which was impossible, but nobody knew it—he researched. Some of his critics had stated

that Oberth's whole theory was useless because of one single fact. You could not bring liquid oxygen and a fuel, say gasoline, together for continuous combustion. Such a mixture would never burn; it would always explode.

This was a serious criticism and it came from people who had long experience in handling liquid gases. It was a point to be investigated, and Oberth was perfectly correct in making its investigation his first experiment. Liquid air was poured into an open bowl (liquid oxygen was considered too dangerous) and a very fine stream of gasoline was shot into the bowl and ignited at the same time. It had been a little bit too much and a minor explosion resulted. It did small damage; it also gently pushed out a windowpane. The experiment was repeated and the result was that the critics had been wrong. It did work or, rather, it could be made to work. As a matter of fact, Oberth was quick to see that something took place which had never been observed but which was very advantageous: the burning droplets tore themselves apart and were consumed much faster than had been assumed. This discovery meant that much larger amounts of fuel could be burned in a given space and during a given interval of time than had been

believed possible. For one thing, it made the still theoretical rocket motors much smaller and lighter.

During one of these experiments another explosion occurred; this one was worse and came close to destroying Oberth's eyesight in one eye. It laid him up for several days, but there have been worse rocket explosions since. Oberth spent some time figuring out a theoretically ideal combustion chamber. In general shape it was conical (Fig. 23) and Oberth called it *Kegeldüse*, *Kegel* being the German word for cone. He had several specimens of it built somewhere—I don't recall whether in one batch or one after the other, but I suspect the latter.

While Oberth had stressed the advantages of gasoline as a rocket fuel in lectures, he did not want to use gasoline for his own experiments but looked around for methane (CH_4 , known also as marsh gas) because of a slight theoretical advantage. It could not be had easily in Berlin, which disappointed him because "home in Mediash we have it in commercially pure form from gas wells."

The rocket was to be torpedo-shaped and about 6 feet long, the construction material an aluminum alloy. Nebel took the plans to a factory where the parts were made and after his return they began to work on a parachute release which they wanted to test by means of powder rockets. When they got in touch with a factory of powder rockets, they found that the mechanism developed by the factory for the ejection of complicated starlights was completely satisfactory for their purposes.

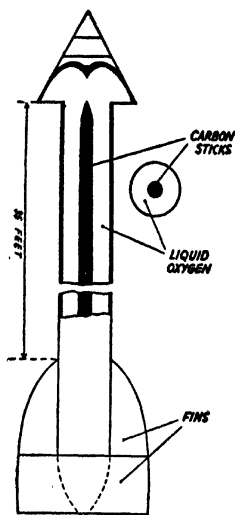
All this consumed time.

Most of the delays would have been avoided if Oberth had had an assistant who knew the industrial establishments of Berlin. But even the most ideal assistant could not have accomplished the job in time. The program, as a program, was not so bad, but it was one for a whole year, with four months added for safety's sake. They did not even have four months.

The public waited for the experiment with an enthusiasm that looks incredible even in retrospect. The demand for information was so great that I had to write an article about rockets literally every day for several weeks. The enthusiasm was such that even a photograph of the spot on the Baltic coast rented for the experiment sold well as a picture postcard.

The UFA Film Co. had announced that the Oberth Rocket

24. Oberth's Rocket for Carbon and Liquid Oxygen.



would probably rise to 70 kilometers, say 45 miles. The place chosen originally had been the *Greifswalder Oie*, a small and perfectly flat island in the Baltic off the coast near the city of Greifswald. But the authorities had refused permission because there is a lighthouse on the *Oie* and the possibility existed that the returning rocket might touch the lighthouse. It was a perfectly idiotic attitude, considering the probable radius of descent from a height of 40 miles. Within that radius the whole *Oie* is only a small speck and in looking at the lighthouse I found it sturdy enough to stand a hit from a field gun. And the "danger"

was a light empty metal shell dangling from a parachute. In view of the adamant attitude of the officials in charge, the *Oie* was finally abandoned and a spot on the coast of the mainland was chosen. We did not tell anybody that the *Oie* was still within the probable radius of descent from 40 miles.

Suddenly Oberth realized, or was made to realize, that he had only a few weeks left, although he had had more time than originally planned. Fortunately for Oberth, Fritz Lang takes time in editing and cutting his movies—on one occasion in the past he was still cutting the last reel while the first was running in the premiere.

Oberth had to change his plans. He designed a special demonstration model. It consisted of a long aluminum tube with several sticks of coal in its center, surrounded by liquid oxygen. The coal sticks were to burn from the top down. Theoretically they were dimensioned in such a way that the consumption of 5 inches of coal would just use up 5 inches of oxygen level. The gases were to be ejected through a system of nozzles at the top of the rocket; the nozzles were to pull the rocket upward, instead of pushing it upward as planned in the original Oberth Rocket. (Fig. 24.)

This system, known as "nose drive"—as distinct from the pushing "tail drive"—offered a great number of advantages. The rocket

did not have to be constructed as sturdily nor did it require an elaborate steering mechanism with gyroscope, relays, and movable vanes. It was better and simpler all around and in all experiments subsequently made the nose-drive rockets performed best. Oberth told me that he had always had that idea in mind, but that he had wanted to keep the nose-drive method to himself. He had sacrificed it only because of the great hurry.

Oberth made more experiments, failed to find a "carbon carrier" which would burn with just the proper speed, and rapidly approached a nervous breakdown. He left town for a week or so—not announcing it beforehand so that Shershevsky called me up to say laconically: "He ran away"—but came back to attend the premiere of the film (October 15, 1929). The UFA Film Co. released a statement that the rocket ascent had to be postponed indefinitely, hinting that the season had too far progressed for reliable weather. Nothing happened for some weeks after that, then Oberth suddenly left for home, releasing a statement that he would sue the UFA Film Co.

Years later, in 1934, he explained in a letter to the new president of the *VfR* that he had not been accountable for his actions at that time. The explosion, he claimed, had given him all the symptoms of shell shock and he had never completely recovered.

Chapter 6:

SUCCESS, FAILURE, AND POLITICS

History has been charged with the duty to judge the past and to educate the present for the benefit of the future. This work does not attempt to do anything as important as that, it only wants to state what really happened.—Leopold von Ranke.

ALTHOUGH the film episode looked like a hopeless failure as far as the practical advance of rocket research was concerned, something good did come of it after all. It came about in a rather devious method, but the focal point of the actual work was the VfR, as had been planned all along.

There had been some changes in the structure of the VfR during the year preceding the non-materialization of the Oberth rocket. Johannes Winkler had resigned as president because of a job of confidential nature; Oberth had been made president and I, vice-president. An office in Berlin had been opened under the direction of a patent attorney by the name of Wurm and the society had flourished. A tally in September 1929 showed a membership of 870 and new members were coming in every day.

By the end of 1929 Winkler had discontinued the publication of *Die Rakete*, but arrangements were made to mail out an information bulletin from Wurm's office so that contact with the members would not be lost. It was this information bulletin which informed the members, a short time later, that the VfR had acquired the Oberth Rocket and that experimentation would be continued by the society.

It would have come to that at any event. The way it actually happened was that I met Nebel on the street one day, by pure accident. Nebel had been wondering whether his recently acquired experience could not be put to some use and he had toyed with the idea of founding a society for the advancement of rocket research. When he told me that I was somewhat dumbfounded. I could not see any reason why he should want to compete with the VfR, but on the other hand he did not sound as if he wanted to. I asked him outright and learned that he did not know of the

existence of the society; Oberth—then president of the VfR—had never mentioned it to him. Nor had Oberth ever called Nebel's attention to any of the numerous books on the subject, save for his own which Nebel had begun to read dutifully only to give up on page 20 or so.

Naturally I brought Nebel and Wurm together. Oberth returned, and a general meeting took place in Wurm's office. Aside from Wurm and me there were Nebel and Oberth, glowering at each other across the conference table, and a young engineer by the name of Klaus Riedel (pronounced *Ree-del*) who had just joined the VfR and wanted to help.

That first meeting resulted in one decision: the Oberth Rocket existed in parts, but some bills had still to be paid and without payment of these bills we could not get the parts. We voted that the VfR should try to pay these bills and have the rocket assembled. That was done and we also acquired Oberth's equipment which was still on the movie lot, the heaviest piece being the launching rack that had been built for the Oberth Rocket.

As soon as it was assembled disagreement began. We all were sure that it would not work; even Oberth agreed. That was the point where agreement ended. Nebel revived a suggestion he had made before, during the last days of the UFA episode. He wanted to put one of Sander's most powerful powder rockets inside for a faked ascent—or for an explosion—just as long as something could be shown to the public. When we all yelled at him in utter indignation, he was mainly surprised; he did not understand such a reaction. Nor did Oberth understand the equally violent reaction that greeted his proposal. He wanted to sell the rocket to a circus in Mediash and use the money to build a better one. It was finally decided not to do anything with it.

Then Nebel revived his old idea of a rocket for liquid fuels, not designed for any performance in particular, but merely designed to function. And that rocket was to be of the smallest possible size. For this reason Nebel called it the *Minimumrakete* or, abbreviated, *Mirak*. Oberth did not like this idea very much—he had rejected it previously, during the UFA experiments—because he was of the opinion that a liquid fuel rocket should show its superiority by having a better performance than any existing powder rocket. But in this case he was overruled; we all agreed that a small rocket that worked was far preferable to a large one that didn't, and Nebel

was charged with the job of drawing a preliminary design.

By this time the funds of the VfR were exhausted and Oberth and Nebel spent several weeks trying to raise funds from scientific foundations. The final result was nil; those societies or foundations either had empty coffers or else what funds they had were earmarked for specific purposes. But that unsuccessful treasure hunt yielded an unexpected result.

There existed a government-sponsored institute by the name of *Chemisch-Technische Reichsanstalt*, the Reich Institute for Chemistry and Technology. This institute did some work of its own along the lines of the Bureau of Standards. But it also tested industrial inventions and processes and testified as to their value. Originally the *Reichsanstalt* had been approached for money. It did not have any funds available but its director, Dr. Ritter, suggested that a rocket motor for liquid fuels be demonstrated to him. If the demonstration turned out well, he would issue a certificate and that should be a great help in approaching other institutions.

It was a good suggestion and we lost no time in accepting Dr. Ritter's offer. Oberth's *Kegeldüse* was made ready for the test and Nebel hoped to get his *Mirak* in too, but it was still incomplete when the day of the test came. I am tempted to say that it was just as well, because the day of the test was one of terrible weather. All through the day it poured; it had poured the day before and it was still pouring the next day. The test was made in the open, in a clearing in the pine forest close to a small shack which offered some protection. But it was as wet inside the shack as out because everything was permeated with moisture; the clouds were hanging so low that they obscured the boughs of the trees.

The *Kegeldüse* had been rigged up on a registering scale and the whole assembly had been placed in a shallow slit-trench. Handling liquid oxygen under these conditions was pretty much a sleight-of-hand trick. Liquid oxygen, having a temperature of close to 200 degrees below freezing Centigrade, rapidly draws all moisture within reach out of the air and freezes it around pipelines, valves, and other points which should not be covered with ice. There was much moisture in the air on that day, clouds of ice crystals formed wherever liquid oxygen was poured from one container into another, and I saw one pipe collect a quarter-inch layer of ice in less than a minute. But, despite the great waste of liquid

oxygen, Riedel—who did most of the actual handling of the equipment—finally got the rocket motor going and the press photographers somehow succeeded in getting a few pictures in spite of the raindrops on their lenses.

Dr. Ritter certified that the *Kegeldüse* “had performed without mishap on July 23, 1930, for 90 seconds, consuming 6 kilograms of liquid oxygen and 1 kilogram of gasoline, and delivering a constant thrust of about 7 kilograms.” (One kilogram equals 2.2 pounds.)

The demonstration at the *Reichsanstalt* was Oberth’s last experiment in Germany. Officially he was still a teacher of mathematics at the high school at Mediash, and as far as that high school was concerned the whole year of work for the UFA Film Co. had been simply a leave of absence. While Oberth’s endeavors were appreciated by his superiors, there was a limit to the time a man could be on leave and still retain his job. He now had to return and he did it gladly. Pocketing the certificate Dr. Ritter had issued and thinking nasty thoughts about everybody he had met, Oberth went happily home to Mediash.

Those six months between Christmas 1929 and the official test run of the *Kegeldüse* had not been idle by any means. The first *Mirak* had been built during that time and a good deal of publicity work had been done. Unfortunately a tragic and actually dangerous note had crept into that work.

It had begun with a public meeting in the lecture hall of the General Post Office in Berlin. On that night, April 11, 1930, the completed Oberth Rocket was displayed for the first time. Among those present were not only representatives of large firms and institutions but also Hermann Ganswindt, Johannes Winkler, and Max Valier.

Valier told me that night that he had “said good-by to powder rockets” as I would see soon, and I did see it about a week later, on April 19. Early in that year Valier had come to terms with Dr. Heyland, the director of a firm with the clumsy title Association for the Utilization of Industrial Gases. Among other things this firm manufactured liquid oxygen and Valier had built a car which was propelled by a liquid fuel motor for liquid oxygen and gasoline. The large vehicle made a long and lumbering run; it was evident that the motor did not work well and the flame was reddish and smoky, certain signs of poor combustion.

But Valier was sure that he could improve matters soon. He wanted to have the car ready for a demonstration during "Aviation Week" which had been scheduled in Berlin for the week from May 25-31, 1930. The Week consisted of public lectures, documentary films, some inexpensive air hops over the city, and an exhibit on Berlin's most important square, the Potsdamer Platz. The *VfR* was supposed to take part in that exhibit; unfortunately it kept raining most of the week and we therefore moved our Oberth Rocket, the *Mirak*, the *Kegeldüse*, and our other exhibits to the large department store of Wertheim's, situated on the same square. The weather being what it was, our exhibit found many more visitors than the rain-soaked sports planes and gliders outside.

Valier and I met once more on May 14 or 15. He was confident that his improved car would draw a record crowd.

Two days later when I came home at night I found a wire on my desk: Max Valier was dead! It was a Saturday and he had worked late in Dr. Heyland's empty factory. Apparently he had made several test runs of his motor—"idling" it without actually letting the car run—which had turned out well and he had observed another run at close range. Suddenly the motor exploded and a large steel splinter cut the aorta; he bled to death before anybody could do anything about it.¹

It was especially tragic in view of the fact that nothing had ever happened to him during all his dangerous and useless experiments with powder rockets. He died while engaged in his first really useful experiment, although the idea of mounting his motor in a car was, of course, ridiculous. And it was even more tragic since Valier's death gave rise to cries to outlaw rocket research. It may have been these cries that influenced Dr. Heyland to break off negotiations concerning collaboration with the *VfR*.

The demonstration run of the *Kegeldüse* at the *Reichsanstalt*, which we made soon afterward, was a "test" in another respect too. We wanted to see whether reports on that run would cause these cries to be renewed. It did not happen, but we decided "to keep further casualties secret."

For this reason the experiments with the *Mirak* were not made in Berlin. It so happened that the grandparents of the young engi-

¹ Valier was not the first victim. About a year earlier an adolescent boy had been killed by the explosion of a homemade powder rocket while trying to build a large model of the Opel rocket car.

neer Klaus Riedel, mentioned in the preceding chapter, owned a farm near the small city of Bernstadt in Saxony. We made sure that liquid oxygen could be had within easy driving distance and then Riedel and Nebel left with the *Mirak*, a set of tools, and a box of spare parts. Their reports read about as follows: "The *Mirak* burns, but the recoil is too small to be measured with our home-made thrust meter, probably a pound or so." Then: "The *Mirak* now produces a recoil of three or four pounds." Some time later: "The recoil of the *Mirak* is slightly higher than its own weight; it would rise if we released it." And in September 1930: "The *Mirak* has exploded, no harm done; we'll come back and build a new one."

When we put these reports into our mimeographed bulletins by means of which we held the *VfR* together, two members saw fit to reveal that they were wealthy. One of them, an engineer by the name of Dilthey, donated approximately \$1000 in cash, in two installments. Another one, a manufacturer by the name of Hugo A. Hückel, sent only \$100, but he promised the equivalent of about \$150 every month, provided that none of it would be used for anything but experimental work. He absolutely refused to pay postage or carfare or delivery charges—nothing but bills for machinery, tools, gasoline, and oxygen could be charged to him.

It does (and did) sound somewhat funny, but it was a basis to build on. What was needed now was a permanent proving ground, an equivalent of the shack and the open field at Bernstadt. Nebel drove around in the outskirts of Berlin looking for inaccessible places and he found several—an abandoned factory here, an unused tract of land there, a small island in a lake elsewhere. One of these places looked best and he checked on its ownership, etc. Then it looked ideal.

It was a tract of land about 2 square miles in area, difficult to find, and situated in the district of Reinickendorf near the northern periphery of the city, a typical worker's suburb. Two roads led into the vicinity, but one of them was so bad that a city ordinance forbade its use by motor vehicles. I still wonder why the use of the other one was permitted. At the point where these two roads met an old army garrison stood; it was used as local police headquarters.

The place chosen was across the street from the police garrison, but did not border the road. A secondary dirt road branched off there, leading for 1000 feet or so through a conglomeration of small

single-family houses, minor manufacturing establishments half of which were idle, truck garages, and shacks of uncertain purpose and use. After you had negotiated that dirt road you came to a wire fence which enclosed the 2-square-mile tract.

The owner was the City of Berlin and to the municipal officials in charge it must have been something in the nature of a white elephant. To make it usable for manufacturing or settlement purposes would have required an enormous capital investment. Not only that, but a new road was urgently needed.

The place itself was hardly suitable for anything. Half of it was hilly and covered with trees, and some of the depressions between the hills were swampy. To make it worse from a businessman's point of view, the jurisdiction was somewhat doubtful. During the First World War, when the police garrison had been an army garrison, the place had been used to store ammunition and the War Ministry had erected storage buildings. These were massive concrete barracks with walls a foot thick, surrounded by blast guards in the form of earth walls, 40 feet high and about 60 feet thick at the base.

The earth walls had slits to make the buildings accessible for vehicles, but the slits were a little too narrow for large motor trucks. The roads connecting the various buildings could hardly be seen any more and the buildings themselves had only a very few windows.

While the ground itself belonged to the city, the concrete buildings and earth walls belonged to and were under the jurisdiction of the War Ministry. The city might have liked to rent the place, but the War Ministry insisted that no damage of any kind must be done to its buildings and earth walls and that, of course, prevented any business deal.

We had to make an enormous number of promises. We were to use only one of the two gates, we were to occupy only two of the buildings and were not to enter any of the others (there were five or six more, all perfectly empty as we quickly found out), we were not to make any changes in the two buildings we were permitted to use, and we were not to move in machinery and/or equipment which could not be moved out within forty-eight hours. We promised everything and then rented the place for a nominal sum—some \$4 per year—and received the key to the smaller building on September 27, 1930, which date we proclaimed to be the "birth-

day" of our testing ground. Nebel called it the *Raketenflugplatz* (rocket airdrome) and it became known in interested circles all over the world.

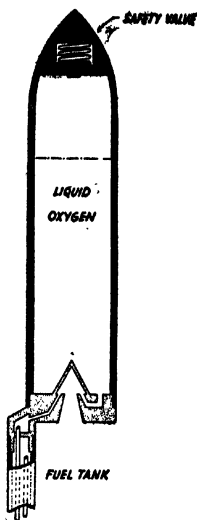
The smaller building next to the gate, not surrounded by an earth wall, had only one storey. It was an oblong of about 30 by 45 feet, divided into two sections by a massive partition, one section being about twice as large as the other. The smaller section was subdivided again so that it had three rooms, the large one being four times as large as either of the two small ones. It had obviously been the guardhouse, with a rest room and an office for the officer in charge and a room for the soldiers of the guard. A replica of this building could be found near the other gate. During the interval between the time the guard had moved out and we had moved in, somebody had used it to store lumber which was afterwards forgotten. When we finally got the door open we found a solid layer of thoroughly rotted wood, a yard thick. It was a full day's work to drag this wood out into the open, to burn it, and to clean the house.

After that Nebel and Riedel set up a bachelor household in the two small rooms and used the larger room as temporary storage space for our equipment. It consisted of the Oberth Rocket and a full-size wooden model of it, as well as the iron launching rack for the Oberth Rocket. The wooden model was later mounted on a pole near the road, pointing in the direction of the testing ground. Then we had the second *Mirak*, which had been completed in the meantime, and the stand in which the first *Mirak* had been tested at Bernstadt. The rest was odds and ends.

This room later became a combination office, reception, conference, and board of directors' meeting room; I called it the *chambre à tout faire*. But during the winter it became an incredible jungle of machinery and raw materials. We wrote hundreds of letters to any firm manufacturing something we could use, explaining what we wanted to do and asking for contributions which would help us a lot and not hurt the contributor. We did not ask for cash, we asked for raw materials, unused machinery (unused, that is, by the man or firm who owned it), for tools and similar things. And we got them: boxes of hand tools, aluminum in sheets and rods, magnesium alloy in rods and seamless tubes, angle iron, screws, nuts, bolts, pots of paint, a drill press, and a small lathe—a whole machine shop came in piecemeal.

Somebody, in an hilarious moment, even wrote a letter to the

ROCKETS



25. Cross-Section of the "Head" of Mirak 2.
Solid black indicates aluminum; dotted area indicates copper.

Department of Internal Revenue asking for a waiver of the tax on the gasoline we would use for our experiments, transportation, etc. To our great surprise it worked, bringing the price of gasoline down from about 80 cents per gallon to something like 13 cents per gallon.

Our program was as simple as it was definite.

There was to be no nonsense about rocket cars. We had made up our minds that a rocket could be good only as a rocket and we were going to build rockets. Oberth had been perfectly right in that respect. But we also decided that there was no use tinkering any longer with the Oberth Rocket. We

wanted to keep it as a museum piece. It later stood like a big gleaming airplane bomb in the *Chambre à tout faire*, causing visitors to throw away their cigarettes in a hurry.

Our first job was to make the second *Mirak* work.

It was a replica of the first, except that it was slightly larger in size. When Nebel had drawn up the design of the first *Mirak* he had followed the pattern of a powder rocket as closely as he could. Like a powder rocket it consisted of a "head" and a "guiding stick." The latter was a long thin aluminum tube which served as gasoline tank. The "head" was made of cast aluminum and machined to size; it looked like an artillery projectile. The nose could be removed to fill in the liquid oxygen and it contained a safety valve. (Fig. 25.) The bottom of the head was made of copper and carried a combustion chamber in the center, a small replica of the *Kegel-düse*. The combustion chamber, therefore, formed the bottom of the liquid oxygen tank. It was assumed that in this way it would serve two purposes: the liquid oxygen would cool the rocket motor while the heat from the rocket motor would evaporate some of the liquid oxygen, thereby creating sufficient pressure to feed the liquid into the combustion chamber. The gasoline was to be fed into the combustion chamber by means of carbon dioxide pressure,

produced by a carbon dioxide cartridge of the same type that is used for making soda water. That cartridge was carried in the end of the tail.

The launching rack of the *Mirak* was equipped with a simple gear which could be turned from a distance. By turning that gear the carbon dioxide cartridge was discharged in the customary manner.² But the launching rack was also provided with a clamp that held the *Mirak* tightly so that it did not rise when fired but only pulled that clamp. And the pull could be measured.

The second *Mirak* performed like the first: it would have been just powerful enough to lift itself off the ground. Finally, like the first, it exploded. The hot combustion chamber made the oxygen develop more pressure than the tank could stand or the safety valve could handle. We came to the conclusion—which was also verified mathematically—that the liquid oxygen could not be used to cool the rocket motor; that had to be done either by the fuel or by a separate cooling water-jacket.

The second *Mirak* blew up in the spring of 1931.

It was decided to do two things simultaneously. A third *Mirak* was to be built, with the rocket motor below the bottom of the liquid oxygen tank. For better balance it was to have two tails; the second tail was to hold compressed nitrogen gas so that the carbon dioxide cartridge could be discarded. The parts for this third *Mirak* were made except for the motor. To build a better motor was the other thing we had decided to do and that had to be done first.

There was some delay because that job needed much preparation. Now that spring and better weather had come, we began to occupy one of the large buildings and change it into a laboratory and machine shop. This larger building had a second floor; not

² In some English and American books and magazine articles it is stated that the second *Mirak* differed in various respects from the first, mainly in having a ceramic-lined combustion chamber. This is due to a series of misunderstandings which occurred when I explained the story of the *Miraks* to G. Edward Pendray, one of the founders of the American Interplanetary Society (later the American Rocket Society), when he visited the *Raketenflugplatz*. The misunderstandings were due to the fact that Pendray did not speak German and that my English was very poor. What I meant to say, but apparently didn't, was that one specimen of the *Kegeldüse* had been tested with a ceramic lining. As was to be expected the lining cracked and one piece of it blocked the exhaust nozzle, causing the combustion chamber to explode. That had been before the first *Mirak* existed even on paper.

far below the roof a ceiling of 2-inch planks, resting on 8 x 8-inch wooden beams, had been built in. This ceiling was at the same level as the crest of the earth wall around the building, and a door led to a narrow bridge which ended on the crest of the earth wall. Walking over the bridge and down the earth wall we came to a small depression in the ground and this was chosen as the site for the testing stand.

The testing stand was the old iron launching rack for the Oberth Rocket, fitted with a balance. The rocket motor was attached to one end of the balance and the tilt of the balance registered on a revolving drum. An insulated oxygen tank and a gasoline tank were buried in the ground at either side of the test stand, each with a nitrogen steel bottle for pressure. The valves were operated by thin wire ropes which led into the top floor of the machine shop. They were connected to large railroad switches and operated by a man standing behind the doorway. The same man also ignited the rocket motor by closing an electric switch. The operator was perfectly safe, but he could not see the test stand either; he followed orders shouted by the man standing on the crest of the earth wall and directing the test.

The procedure was as follows: the rocket motor, which will be described soon, was water-cooled during the test stand runs. It was fitted into a metal container which, in turn, was attached to the balance of the test stand. The cooling water came from a large water barrel standing on the ground just outside that small depression into which the test stand was placed. The water was drained off through a pipe fitted into a hole near the bottom of the container; the pipe ended on the ground a few yards away.

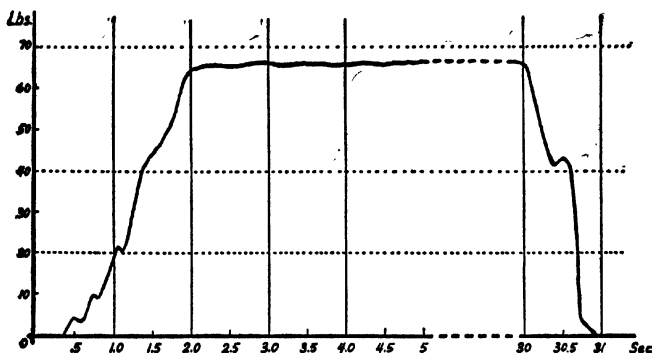
The ground crew's job, after the water barrel and the fuel tank had been filled and the motor had been attached to the balance, consisted of the following procedure: The ignition device was attached to the muzzle of the exhaust nozzle; it was actually a kind of small powder rocket but with strange qualities. The powder had been compounded by the chief chemist of a large pyrotechnic factory near Berlin, and it required a specialized chemist's specialized knowledge to produce a powder that did just what we wanted it to do. The main point was that it had to produce a very hot flame, but it also had to burn for at least ten seconds and with little generation of exhaust gases; the ignition device was not supposed to have any recoil. In addition to that, the flame was not to be ex-

tinguished either by water or by a jet of cold compressed gas. A thermite cartridge approximately filled our needs but was too hard to ignite; we wanted electric ignition too. The chemist, Dr. Feistl, after hearing all these requirements said that it could be done, and he delivered a dozen capsules only a week later. They proved excellent.

After that device was attached, the clockwork of the registering drum was wound up, and after that the liquid oxygen was poured into the oxygen tank. Then the ground crew scrambled to safety, leaving only one man behind who turned the stop cock in the cooling water line. When he too was under cover the test really started. There was a definite sequence in the orders shouted by the observer. It went: "*Feuer!—Benzin!—Sauerstoff!*" "Fire!—Gasoline!—Oxygen!"

At "Fire" the electric switch was closed, and it ignited the small powder tube which jetted its flame horizontally across the mouth of the exhaust nozzle. When that flame was well established the shout for gasoline was answered by a spout of yellow fire from the rocket motor. The call for oxygen followed immediately. The flame grew first bright and then bluish, shortening rapidly at the same time. The sound produced by that short and sometimes hardly visible flame resembled the roar of an enormous waterfall which kept up until the switches were closed or the fuel gave out. Test runs varied in length from thirty to ninety seconds. When Mr. and Mrs. Pendray of the American Interplanetary Society visited the *Raketenflugplatz* in April 1931 we could demonstrate a fine test run.

By that time the preliminary experiments had settled down to a standard fuel—gasoline—and a standard motor which was generally referred to as "the egg" because it was about the size and shape of an egg. It was made of two sections of spun aluminum—almost pure aluminum—which were welded together. The two liquids were jetted in through attachments in the lower end of the combustion chamber. (For diagram see Fig. 28.) The complete motor without the cooling water-jacket weighed not quite 3 ounces, and it produced a thrust of 32 kilograms (70 pounds) after the first run. The first run was usually poorer, producing from 28-30 kilograms, but the motors improved with use. Since they consumed around 160 grams of gasoline and liquid oxygen per second, the exhaust velocity of the blast must have been almost precisely 2000

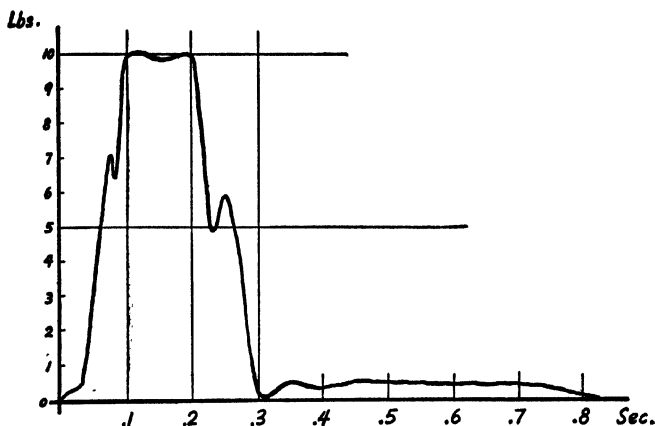


26. Thrust Diagram of a Liquid-Fuel Motor.

meters—some 6600 feet—per second. For this reason the “egg” was officially called the “160/32 standard motor.” (Figs. 26 and 27.)

I cannot say who invented it; it is almost impossible to tell who invented anything at the *Raketenflugplatz*. The *Kegeldüse* was Oberth's invention and the first *Mirak* was Nebel's, but after that almost any device or development was the result of informal talks and conferences between three or four or even five or six people. We never paid any attention to the question of who had thought of what, knowing that it was a long way from our experiments to definite shapes, and knowing also that our glory was a collective glory. If the question of who invented the standard motor were important, I'd feel inclined to give most of the credit to Riedel.

The standard motor was not only powerful, it could also be regarded as safe after it had been through one or two test runs. We had just enough accidents to keep us from getting careless. Once a motor burned through at a faulty place in the welding seam with the weird effect that there were two jets of fire, one vertical and one horizontal, the latter carrying a steaming spray of water with it. Once the man at the controls pulled the oxygen switch first by mistake and the whole motor blew up—a piece of it deeply imbedded itself in a spade handle which I kept for years as a souvenir. It would have penetrated two inches in living flesh. Another time the whole welding seam broke and the top of the motor shot skyward. The violent explosive combustion resulting from the jets of oxygen, gasoline, and water meeting in midair



27. Thrust Diagram of a Small Commercial Skyrocket.
The thrust reaches 10 pounds, but lasts for only one-tenth of a second. The latter part of the curve shows the thrust produced by the solid section of the powder charge.

almost tore the test stand apart before the man at the controls could turn the pressure off.

But practically all of these accidents happened during first runs and even then we sometimes knew that they were coming. If the motor roared like a waterfall with a steady and fairly small darkish flame everything was fine. When we suddenly got a bright flame and machine-gun staccato it was better to duck quickly and with a great disregard for curiosity.

This was the motor that was to go into the third *Mirak*. But the third *Mirak* was never built, or rather it was never assembled.

It was not assembled in the end because we had something better. But at first it was simply because we had too many other things to do. Nebel, when asking prospective donors of machinery and tools for a donation, had had to promise occasionally that he would invite them for a demonstration when ready. When we could fulfill this promise, Nebel had the idea that these demonstrations could be used to augment our income for which we were dependent on membership fees and on Hückel's generosity. We would invite engineering societies of various kinds to witness test runs for a flat fee of say \$50 regardless of attendance. When these visitors

came we would usually test one or two new motors and hold a tested one in reserve, in case something went wrong. The scheme greatly helped to improve our finances, but it prevented us from doing something with the third *Mirak*.

It also helped to deprive us of the honor of having sent the first liquid fuel rocket in Europe up into the air.³ That first European liquid fuel rocket took off on March 14, 1931, but it was not ours; it was Winkler's. The rocket stood about 2 feet high and weighed 11 pounds of which 3½ pounds were fuels. It looked like a prism placed on end and consisted of three tubular tanks, partly covered with sheet aluminum much in the manner of the old box kites. One tube held liquefied marsh gas, the other liquid oxygen, and the third "an inert gas under pressure," which was Winkler's way of saying "compressed nitrogen." The motor consisted very simply of an 18-inch piece of seamless steel tubing, placed near the center line of the system. The rocket rose, according to Winkler, to an altitude of about 2000 feet (600 meters) from a field near Dessau. Hückel had paid for the experiment and, although we felt a bit foolish that Winkler's private tinkering had built a rocket before we had, we liked the news. A liquid fuel rocket had performed well. It could be done. That meant that we could do it too.

But some other things happened in March that pleased us less; in fact they comprised our two pet hates: rocket automobiles and powder rockets. The rocket car in question was Max Valier's last experiment. The chief engineer of the firm owned by Dr. Heyland, a man by the name of Pietsch, had designed and built a new rocket motor for this car. It seems to have been cooled by its own fuel and it was capable of delivering a thrust of 160 kilograms (about 350 pounds) for a period of a few minutes. The weight of the motor was 18 kilograms. The car made two public (and probably several secret) test runs on April 11 and on May 3, 1931. While the thrust of this rocket motor was unusually high and the duration of the test remarkable, the efficiency must have been poor. The flame was red and smoky, signifying incomplete combustion.

If the revival of the rocket car was bad, the new powder rockets were, from our point of view, worse. They were the invention of an engineer by the name of Reinhold Tiling (pronounced *Tee-link*)

³ Actually liquid fuel rockets built by Professor Robert H. Goddard had taken off before that date, but Goddard did not release anything about his experiments until 1935.

who resided at Osnabrück. The first *public* demonstration took place April 15, 1931, at the shore of a lake near Osnabrück. Tiling, who had the financial backing of one Count von Ledebour, must have worked in secret for a long time because the rockets he displayed then were finished products.

They consisted of a streamlined aluminum body, housing the rocket proper, and four long fins. There was no parachute. The functioning of Tiling's landing mechanism is reported wrongly with annoying consistency, mainly because Tiling patented a misleading description. (U. S. patent No. 1,880,586 of Oct. 4, 1932.) The patent states, in essence, that the rocket's four fins will spread out at the peak of the ascent and act like the blades of an autogiro.

Actually Tiling's rockets did not use that system at all. Two of the fins remained fins, while the two others snapped out like the blades of a pocket knife. The two fins transformed the rocket into a glider, not into an autogiro. The arrangement worked well, provided the air was calm. It was better looking but much less effective and much less versatile than a parachute. The Tiling rockets had an over-all length of about 6 feet, and they rose to altitudes varying from 1500 to 2500 feet. They never showed any improvement, just because Tiling had demonstrated a finished product to begin with.

We were still busy with demonstrations of our rocket motors and with the enlargement of our workshop.

After quite a number of demonstration runs and after the visit of the Pendrays, Nebel felt that he could do with a vacation. There was an Aviation Week of some kind in Kiel and Nebel decided to go there, taking the Oberth Rocket along for exhibition. There were no demonstration runs for several weeks and Riedel and I had time to straighten out odds and ends and talk things over. It had been vaguely agreed upon that the third *Mirak* should be assembled, but that was no definite promise.

Riedel had another test in mind which we had planned together quite some time earlier but had not been able to perform, partly because of the pressure of other work, partly because Nebel would have frowned upon anything that was not directly connected with his third *Mirak*. The idea was to take two pieces of magnesium tubing of the same capacity as the *Mirak* tails, put one of the standard motors between them, and measure the thrust that would be developed under those conditions. We talked for a while about

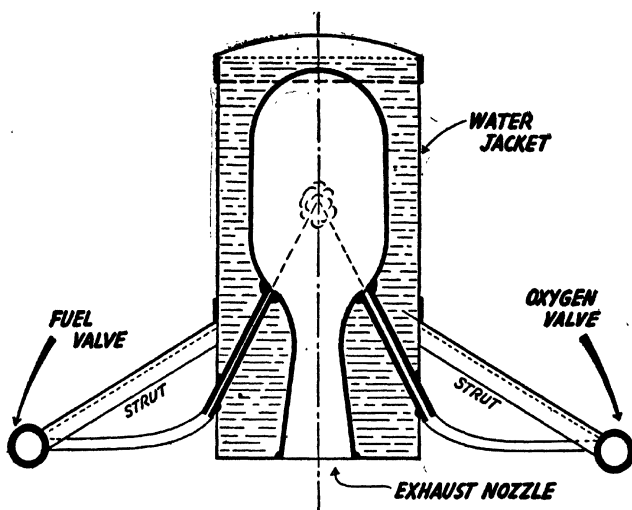
the simplest possible arrangement for such a test and then just sat and looked over our *Raketenflugplatz* which had grown very beautiful with the coming of spring. The hilly part was covered with the young green of pine shoots and new beech leaves, the depressions between the hills were full of young birch. Crickets sang in the high grass and frogs croaked somewhere in the distance.

Only a few days later Riedel called me up in the office, telling me that he had "taken the secret baby out for a test run" the day before. He did not expect anything to happen; it was well weighed down with oversized valves, a large cooling water-jacket, and heavy struts. "But the beast flew! Went up like an elevator, very slowly, to sixty feet. Then it fell down and broke a leg."

I inquired just what "a leg" meant. "A fuel line," chuckled Riedel. "Home in Mediash that wouldn't have happened." This accidental flight had taken place on the 10th of May; on the 14th the rocket was repaired, lightened, and ready for the first planned ascent. The only thing lacking was a parachute. We did not have one ready and we were much too eager to wait. The two tubular tanks of the rocket were inserted into two stovepipes which served in lieu of a launching rack. The spring-operated valves we had were too heavy so we used light turn cocks which had to be opened by means of "keys" mounted on broomsticks. It was done through the open and sand-bagged window of one of the buildings.

In spite of all the makeshift the "flying test stand" took off with a wild roar. It hit the roof of the building and raced up slantwise at an angle of about 70 degrees. After two seconds or so it began to loop the loop, rose some more, spilled all the water out of the cooling jacket, and came down in a power dive. While it was diving the wall of the combustion chamber—being no longer cooled—gave way in one place, and with two jets twirling it the thing went completely crazy. It did not crash because the fuel happened to run out just as it pulled out of a power dive near the ground; actually it almost made a landing. Examination showed that it was intact save for the hole in the motor. We could not examine it at once since we were dizzy from watching and jumping out of the way and had to sit down in the grass for a moment. In retrospect it seemed as if all this took place very close to the ground, but my notes say that we estimated maximum altitude as about 200 feet immediately afterward.

This was the beginning and end of Repulsor No. 1 (Fig. 28). We



28. Original Sketch for Riedel's First Repulsor.

The two tubular tanks were to be attached to the struts outside of the two valves. In actual construction the struts were placed below the fuel lines.

took that term straight from Lasswitz's novel since we wanted to avoid the word rocket because it implied powder. And we could not call these machines *Miraks* any more; they were something else.

Work on Repulsor No. 2 began the same night. We used the same tanks but substituted another motor. The struts were eliminated and better valves were substituted. We decided to do once more without a parachute, but we connected the tanks by circular aluminum hoops and took a large circular disk of sheet aluminum and cut it into four quarters. These were attached to the lower hoop to serve as fins. The repulsor was to stand on these fins on the ground so that no launching rack would be needed.

No. 2 was ready on Saturday, May 23, 1931. It happened to be an exceptionally beautiful day. At first the repulsor was fueled with oxygen only since we had to find out how long it would take to build up the necessary pressure of 300 pounds per square inch in that particular tank on that particular day. The time required was just short of four and one-half minutes. One of the mechanics then opened the valve which let the oxygen escape through the

motor and the exhaust nozzle. He swore that he felt a noticeable recoil.

In this and in all later repulsors the oxygen was fed into the rocket motor by its own gas pressure; a short waiting time of a few minutes was all that was required. The gasoline was fed into the motor by means of compressed nitrogen. Since a fuel tank was filled to only one third of its full capacity at the most, there was enough empty space on top of the fuel for the compressed nitrogen.

After the oxygen pressure test we had some coffee and butter-cake in the open before we got the repulsor ready in earnest. While Riedel waited, wristwatch in hand, for the oxygen to build up pressure, I climbed a low hill to have a vantage point from which I could not only see the repulsor but also look over most of the *Raketenflugplatz*. From down below I heard the shouts of "Ready! —Fire!" and saw a white flame shoot out of the nozzle. It shortened quickly, became less bright, and began to roar. At the same instant the repulsor rose off the ground, slowly at first but accelerating rapidly. It climbed to about 200 feet and then turned sideways, like a car taking a curve. In that position it raced across the whole place, still under full power. It slowly lost altitude and it also slowly turned around its longitudinal axis while in flight. The four aluminum fins reflected the red rays of the setting sun like mirrors.

We saw that the repulsor would land outside the *Raketenflugplatz* and started on a wild pursuit, by car, motorcycle, and bicycle. We knew that people often walked in the forest outside the fence and we had visions of horrible slaughter. Fortunately the repulsor had not done any other harm than breaking off a 2-inch branch of a stout tree. When we found it, it was hanging in the smaller branches some 30 feet above the ground, totally smashed. The distance from take-off to tree was 600 meters, about 2000 feet.

That night we wrote two very triumphant letters, one to the American Rocket Society in New York and one to Nebel in Kiel. And then we quietly put the parts of the third *Mirak* in a big wooden box. After that it was repulsors.

No. 3 was built within a few days, and it was a greatly improved model. The two fuel tanks were placed much closer to each other than previously. They were only about 4 inches apart and were held in place by two sets of aluminum braces that jutted out for an inch on either side, fitting into U-channels of aluminum screwed to a wooden launching rack. The bottom braces also carried the

parachute container, a vane can some 3 inches in diameter. It had a fairly loosely fitting lid with a hole in the center through which the main shroud of the parachute was threaded, and in this way the lid was not lost when the parachute was ejected from the container.

The actual ejection was produced by a thick disk of cork which carried a small charge of ordinary black gunpowder. The charge, in turn, was ignited by a timing device of the type used by photographers. The timing device was started by the rocket itself when it pulled out of the launching rack; it was set for the time interval that was calculated to elapse until the repulsor reached peak altitude. This solution, presenting as it did a mixture of mechanical and pyrotechnic principles, was not quite satisfactory from a theoretical point of view. It was, I am tempted to say, theoretically unclean. But it was reliable.

Repulsor No. 3 was tested on a beautiful afternoon early in June. It quickly climbed to 1500 feet. About then the fuel was exhausted and about then something went wrong: the parachute was ejected but much too early. Either there had been more fuel in the repulsor than we had thought or else the timing mechanism had been set wrong. At any event the rocket was still climbing at a fast rate when the parachute blossomed out. It was effortlessly torn off, the repulsor rose for at least another 600 feet, but because of the momentary pull of the parachute it rose at an angle of about 60 degrees while it had climbed almost vertically before. Describing an enormous arc, the repulsor landed outside the *Raketenflugplatz* like a howitzer shell—by coincidence in the same clump of trees where No. 2 had found its end. It buried itself more than a foot deep in the hard forest soil, completely smashed.

These early experiments decided two very important questions: the proper position for the rocket motor and the proper place for the parachute container. The nose drive, with the rocket being pulled by the motor, proved far superior to the originally contemplated tail drive in every respect. The rocket was not only more stable during the ascent, it was also easier to design. The nose drive eliminated, at least for experimental models, the clumsy, expensive, heavy, and mechanically difficult steering mechanism. It seems to be virtually impossible to build a mechanism of this type for small rockets—Goddard's latest models were probably near the lower size limit. It does work well in large rockets of the V-2 type. The nose drive selected by us also allowed us to put

the parachute in its proper place: the extreme tail end. Oberth had thought of putting it in the nose compartment. One night, when making a diagram of a trajectory, I realized why it did not belong there.

The ideal case was, of course, that the parachute should be ejected at precisely the instant when the rocket begins to fall back to the ground. But a timing device might be somewhat off and eject the parachute a few seconds too early or a few seconds too late. If it were ejected too early the still rising rocket would run into its own parachute. If it were ejected too late, after the rocket had turned over in the air because of its stabilizing fins, the same thing was likely to happen. In either case it was likely to crash. But if the parachute were located in the rear that would not occur. If it were ejected a little too early it would merely halt the still moving rocket. If it were ejected too late the rocket would fall for a few dozen feet without a parachute. For similar reasons I had advocated that the timing device should be set for "too late."

Riedel had placed the parachute in the tail in No. 3 because of my insistence and against Nebel's wishes, but he had given in to Nebel in setting the timer "on time." If it had been delayed No. 3 would not have crashed.

But that was unimportant; three more of No. 3 were built during the next few weeks and one or two more later. They all made fine ascents, but there were a few more parachute accidents of the same kind. The next step was Repulsor No. 4 which turned out to be the perfect model. It was essentially Repulsor No. 3 taken apart and reassembled differently. The motor, enclosed in a small cooling water-jacket, was placed on top as usual; two struts and two fuel lines, forming a four-pronged fork, held it in place. The handle of that fork was the oxygen tank. The gasoline tank was placed in line below the oxygen tank and the vaned parachute container below the gasoline tank.

We called this model the "One-Stick Repulsor" and the older types, consequently, were referred to as "Two-Stick Repulsors." The first of them was tested in August 1931 and reached an altitude of about 1 kilometer, roughly 3300 feet. At that altitude it was only a small dot in the sky. Suddenly we saw a tiny white parachute against the blue background and the repulsor drifted gracefully back to the ground. Several more were built, two of them larger in size but with the same standard motor. The One-Stick Repulsors,

not fueled to capacity (which we did not dare to do because it would have caused trouble with the authorities), reached altitudes of around 1 mile; one that by accident took off at an angle covered a distance of more than 3 miles. Often we released them half fueled because they were sent up for demonstrations and they presented a better spectacle when the ejection of the parachute was clearly visible from the ground.

All the time progress was steady with hardly any disappointments. We had only one partial failure—the test runs of a larger motor. It had been designed as early as April and since we called the small ones eggs I referred to the big model as the “*Aepyornis* Egg,” in reference to the gigantic eggs of the extinct “Madagascar ostrich” *Aepyornis*, which are still found in swamps on occasion.

The *Aepyornis* Egg was expected to yield a thrust of 64 kilograms or 140 pounds; actually it barely made 50 kilograms or about 110 pounds. This partial failure was not conclusive, however, since it might well have been a partial failure of that particular motor. It happened occasionally that one of the standard motors did not perform so well. The tentative designing of a still larger model seemed justified.

There was no further progress during the remainder of that year of success, but things still went well. The UFA Film Co. devoted a large portion of its sixtieth newsreel * to the first year of work in the *Raketenflugplatz*, showing a test run of the *Aepyornis* Egg and the ascent of a One-Stick Repulsor. By that time 87 ascents and 270 test stand runs of rocket motors had been made, not counting the *Miraks* at all.

During the filming of the newsreel one repulsor tore off its parachute and landed on top of a shack, setting the roof afire with the last remaining drops of gasoline. It was an old shack and there was nothing of value stored in it, but it belonged to the property of the police garrison across the road. The police descended on the *Raketenflugplatz* like an invading army and any further experimentation was forbidden then and there.

Long discussions and hearings followed, revolving around the question: “When is an accident just an accident and when is an accident a symptom that something is essentially dangerous?” We

* They were numbered and there was one every week. Number one had been the first UFA newsreel with a soundtrack.

quoted airplane crashes and train derailments, bus collisions and fires from short circuits. Finally a demonstration was staged just for the police, and the order was withdrawn, with five provisions that read:

- A. The weight of the rocket with fuel must not exceed 11 pounds.
- B. The rocket motor used must have made three flawless test runs.
- C. Heavier rockets require special permits.
- D. Flights must be made only on workdays between 7 a.m. and 3 p.m.
- E. No rocket flights are permitted on windy days.

Considering that we worked within the city limits, these provisions were sensible enough.

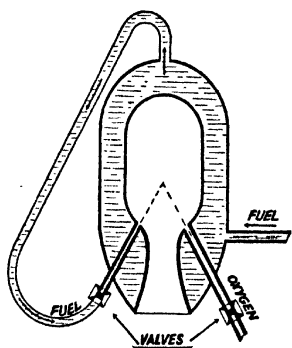
The newsreel and the victory over the police were our last triumphs. What followed afterward was a hopeless struggle against political tension and economic misery. It was a hard winter climatically. And it was the fatal winter under Chancellor Bruening when Adolf Hitler suddenly assumed prominence. It was a winter during which the roster of members shrank to less than three hundred, most of them deprived of their livelihood. It was a winter during which there came many letters saying that no further dues would be forthcoming because "all money belongs to the Führer." Hückel wrote that he could not help us any more and Dilthey disappeared. Six months later his body was found in a narrow cliff-bounded valley. He had met with an accident while vacationing in the mountains.

In order to raise money I went on a lecture tour in East Prussia. At the *Raketenflugplatz* the men struggled along.

In spring the testing arrangement was completely overhauled. A dugout was placed in the earth wall, only 30 feet from the test stand. The pressure bottles were placed in that dugout, to be operated by the observers who were protected by thick wooden planks, peering through a slit less than an inch wide. A number of larger motors were tested, some of them burning alcohol instead of gasoline. The results were, on the whole, satisfactory. (Fig. 29.) A score of repulsor ascents were made too, but things did not look rosy any more.

There were continuous clashes during the meetings of the board of directors except on the two occasions when Nebel was not pres-

ent. When he was attacked everything and everybody. He attacked me for having kept an agreement about mutual information which I had signed on the occasion of Pendray's visit to Berlin. He attacked the new president of the VfR, Major Hanns-Wolff von Dickhuth-Harrach, a retired officer, for having signed a congratulatory letter to Ziolkovsky on the occasion of Ziolkovsky's seventy-fifth birthday. Speaking with a careful imitation of Hitler's mannerisms—they had the same hard southern accent to begin with



29. Alcohol-Oxygen Rocket Motor.
This model circulated the fuel around the combustion chamber before injecting it, thus obviating the need for cooling water. (See Plate XI.)

—he declared that he would leave the VfR and join the army. The latter did not mean that he wanted to enlist; it meant that he wanted to turn the *Raketenflugplatz* over to the army. He made that threat to leave during the same meeting of the board of directors during which he had attacked the president of the VfR and me for having signed the letter to Ziolkovsky.

The result of his announcement was open warfare with Nebel on one side and everybody else on the other. Only Riedel, who, after all, had to live with Nebel, tried to maintain a neutral or even conciliatory attitude. The final outcome of the discussion was, as could have been expected, zero. Nebel said, "All right, we'll postpone that point," but everybody knew that this just meant that he wanted to go ahead without our consent.

Something else happened at that meeting which surprised me at the time and failed to make sense until quite a number of years later. Among our volunteer help there had been a young man who

showed great promise, even though he had not yet finished with college and not yet obtained his degree, simply because of his age. His name was Count Wernher von Braun. His father had just been made *Reichsminister* of Agriculture in the government of von Papen who was then Chancellor.

Prior to the meeting Nebel had come to me and told me that he thought that it would be useful to have the son of the Minister of Agriculture as a member of the board of directors, and he asked me to vote in favor of von Braun's admission to the board. Naturally I had promised to do so and did. The strange thing was that there was not only no objection (only the patent attorney raised a legal point with regard to von Braun's age, since he was not quite 21) but Nebel himself tried to make the others think that he wasn't really in favor of this move.

Much later I realized what had happened. Nebel had hoped to gain access to army circles through von Braun, but he did not want it to appear as if he had caused von Braun's election.

Whether Nebel actually gained anything by that move seems doubtful to me. At any rate after only a few months von Braun resigned to join the army or rather to accept a commission. This commission in the end led to the design of V-2. But that is another story which will be told in a later chapter.

The succession of subsequent events makes as confusing reading now as it actually was. We took it in our stride that Winkler, who had rented one of our buildings from us for a period of a few months and had conducted some experiments there with a high degree of secretiveness, went through a somewhat tragicomic odyssey. He had built a second and larger rocket which resembled the Oberth Rocket in size and shape; it had a tail drive, a nose parachute, and two spherical tanks for liquid oxygen and methane. It was a little over 5 feet high and weighed around 110 pounds. The trouble with this rocket was that it, like the Oberth Rocket, was based on a large amount of computation with only a very slight seasoning of experience. Winkler had made just one full test run in the course of which most of the exhaust nozzle had burned away.

Like the Oberth Rocket the HW-2 (Hückel-Winkler 2—Hückel had provided the cash) was to take off from the Greifswalder Oie. But the lighthouse was still there and the same officials were still in charge—at least the same kind of officials. After months of wait-

ing. Winkler had to leave the unfriendly isle and took his rocket to East Prussia where he finally got permission to test it on the beach not far from the harbor of Pillau. He made his first attempt on September 29, 1932. Nothing happened; icing around and probably inside the valves prevented the fuels from entering the combustion chamber. This turned out to be the lesser evil. During the next attempt on October 6, the valves apparently leaked and permitted a trickle of gases to accumulate somewhere between the tanks and the outer skin of the rocket. When the rocket was ignited this mixture caught fire too and threw the rocket (which had barely lifted itself for 6 or 10 feet) to the ground. It was an extraordinary smashup. Winkler complained afterward that not a single part was usable.

Just before Winkler began this work Nebel had tried to influence Hückel to increase his monthly donation to the *VfR*, even though Hückel had declared in a letter that he would have to discontinue his contributions.

Hückel had insisted that he was financially unable to do so. His sponsorship of the HW-2 was a blow aimed at Nebel.

Nebel, casting around for additional money, sat down and wrote a technically wholly inadequate and in fact senseless "confidential memo on long-range rocket artillery" and went to see Captain Becker, the co-author of *Cranz-Becker: Ballistics*, the most used handbook on ballistics.

The results were maddening and it was small consolation that I could say "I told you so." I had warned Nebel once more—after that meeting which had decided against him—and had told him what the inventor of a new airplane engine had recently experienced. He had approached the War Ministry with his invention and had not heard anything for quite some time. Then he was informed, without a word about the engine, that he had to submit to the following orders: he had to make lists of all of his and his wife's relatives and friends and lists of the restaurants and theaters they frequented. The purpose of these lists was that he would receive orders as to what friends to drop, what relatives to avoid, and what restaurants he had to regard as forbidden. This was before Hitler, in peacetime, "disarmed" Germany.

If something like that happened to Nebel, he was careful not to tell anybody about it. But there were enough things we could see. Soon afterward a burglary attempt was made at the *Raketenflug-*

platz and that attempt, which was in all probability faked, was used as an excuse to fingerprint everybody present. Then a demonstration was ordered, to be made at the army's testing ground at Kummersdorf. The repulsor—it was one of the slightly larger one-stick types—had to eject a red flare at the peak of its trajectory, and it was because of this provision that the members of the board of directors learned about the test at all after it had taken place. One of the mechanics complained to us about the unnecessary work! All of those who knew about it, except Nebel, prayed for failure. It turned out to be a brilliant success.

Since Nebel had failed to notify the board of directors about the demonstration, he naturally could not notify us about the result. But we learned about it through his highly informative complaints. He had been treated in the customary manner which consisted in regarding anybody of a lesser rank than a full colonel as a moron and a useless moron to boot. Further research would, of course, be conducted by competent officers. But Nebel, for bringing the subject to their attention, would be rewarded; he would be regarded as a manufacturer and would receive contracts for the manufacture of a specific part, probably the parachute container.

After that it happened that Tiling came to Berlin and Nebel went to see him. I was not present at that meeting but Riedel was and produced a highly humorous account of it. He told me that Tiling greeted them with the words, "Gentlemen, I don't quite know why I received you—as you must know I am used to deal with nobility only." In spite of this not particularly friendly reception they sat down and began to talk. Nebel offered to join hands with Tiling, the VfR to provide its liquid fuel motors and Tiling to contribute his well-developed rocket body with the sailing-fin mechanism. Tiling coldly refused, saying that he did not see any sense in a collaboration with people who were still at the stage of building small vertical rockets while he, Tiling, was ready to span the English Channel.

Tiling had come to Berlin for a demonstration. But he did not do so well. The day happened to be gusty and rainy and the whole enormous Tempelhof airdrome, where he made his demonstration, had hardly a few hundred visitors. To make matters worse, one of his rockets almost smashed into the grandstand, so that the police intervened and declared the demonstration over for that day.

Tiling returned to his home and set out to build rockets capable of crossing the English Channel.

This, at least, is what he announced. But whatever it was he had really in mind did not come to pass. On October 11, 1933, the newspapers reported that Tiling's laboratory had exploded the previous night. Tiling was dead, as was his laboratory assistant Miss Angelika Buddenböhmer, while his mechanic, Friedrich Kuhr, lived for another day.

It turned out to be the result of great carelessness, just like Valier's death. They had been working late the previous night, compressing not less than 40 pounds of powder into compact tablets. In the middle of that work the catastrophe occurred. It seems that the powder press exploded; pieces of the heavy cast iron press were found all over the ruins. The flame of that explosion reached a large supply of processed and unprocessed powder which was *stored in the same room*. The whole laboratory caught fire instantly, but Tiling and his two helpers succeeded in leaving the burning ruins, their clothes on fire. They threw themselves into a near-by pond. Then Kuhr, who was the least injured, ran to Count von Ledebour's castle to give the alarm. Nothing could be salvaged and medical aid came too late for all concerned.

During the winter preceding Hitler's assumption of power, Nebel got the big opportunity he had been waiting for. It was the so-called Magdeburg Project. The chief provision, or so he said, was that the Project would be entrusted to him personally, not to the VfR. Major von Dickhuth and I agreed readily. It looked like something in which we did not like to see the VfR involved. Much of our worry was groundless because Nebel had accidentally kept the society in the clear. When talking to Captain Becker and other army officers he had insisted that there was no other connection between VfR and *Raketenflugplatz* than the fact that he, Nebel, also was secretary of the VfR, or rather had been in the past. When talking to the representatives of the Magdeburg interests, he had said the same. He could say so with impunity because, if anybody thought of checking up with the Court of Registry, he would receive the answer that the VfR, through its secretary Mr. Rudolf Nebel, had filed under oath a voluntary petition of bankruptcy in February 1930.

Nebel had not asked anybody about that; he had never even told anybody. When Major von Dickhuth and I learned it (in the

spring of 1933), we had the ledgers and correspondence seized and went through those things that were not in the book. It became clear that some 2000 marks, if not more, was missing; that Nebel had resold the tax-free gasoline and not even paid the gasoline bills. Knowing this we were obliged to act—which we would have done anyway—and we submitted the facts to the District Attorney.

But meanwhile the Nazis had come to power and the ensuing conversation ran something like this: "Herr Major, I hesitate to do anything. The man has lived to be forty years without any other record than a case of fast driving. . . . Herr Major, you are accusing a former fellow officer. . . . Herr Major, I have noticed that he wears the Party Armband [the Assistant District Attorney did not]. . . . Herr Major, I can only advise withdrawal of your complaints. These are revolutionary times." The Assistant District Attorney was thoroughly frightened.

Von Dickhuth removed Nebel from the board of directors; later we both resigned. The VfR was dead. Just before it died the Nazis had come to us "to give us directives." As far as we were concerned the "reborn Germany" consisted of two or three meticulously booted and uniformed young men who gave the impression of being homosexuals. Being of the ripe old age of nineteen or thereabouts they carefully patterned their speech after the Führer's, unless they grew excited and forgot to do it.

They were going to reorganize the VfR, but their luck was poor. There were no bribes to be had and by sheer accident the members of the board of directors all happened to be "Aryans." What made life worse for them was that von Dickhuth remembered certain psychological principles and rummaged through his trunks prior to the meeting. He appeared in uniform, with half a dozen high decorations, dress saber clanking against high officer's boots. He literally shouted them out of the house.

The New Order then descended upon the *Raketenflugplatz* where Nebel quickly pledged 500 marks for the "Adolf Hitler Sacrifice"—sending them back to us to collect. The VfR still had 34 marks at that point.

For a while von Dickhuth and I tried to keep the interested VfR members together in another society, but it was a slow death. There was no opportunity for doing anything useful, nor any hope for such an opportunity. Late in 1934 I prepared to leave Germany.

The story of the Magdeburg Project still remains to be told. It began like a story by Jules Verne. A mentally somewhat decrepit philosopher had written a pamphlet about the true shape of the universe. He tried to prove that the earth is the universe, that we live *inside* a hollow globe of the dimensions of the earth, that there is nothing outside that globe, and that the universe of the astronomers is only an optical illusion. Since every crank can find some fellow cranks, the "hollow earth philosophy" had found some too, among them an engineer by the name of Mengerling who was somehow connected with the municipal government of the City of Magdeburg. Being an engineer he conceived the idea of testing the hollow earth theory by means of a rocket. If a rocket going vertically upward crashed among the antipodes, proof would be established.

Now Magdeburg is a proud city. It was a burgomaster of Magdeburg, Otto von Guericke, who performed that famous experiment with the evacuated hemispheres which could not be pulled apart by several teams of horses. Magdeburg would welcome another great scientific achievement of that kind. Mengerling offered his idea. The municipal officials did not believe any of the "hollow earth" trimmings, but they were interested in a spectacular rocket ascent, a man-carrying rocket, if possible.

Mengerling talked to Nebel and Nebel at once agreed. He would be ready at Easter 1933 or, better, at Pentecost or, if they did not want a holiday (Pentecost was an official holiday in Germany), the Sunday after Pentecost. They agreed on the latter date, which was the 11th of June 1933. It was agreed that the rocket could cost 25,000 marks and it was to be shown as the crowning feature of a kind of citywide holiday which would require another 15,000 marks.

Mengerling did not succeed in getting pledges for the whole amount, and since Nebel did not fulfill the contract he got only a part of this. Mengerling later spoke of 3200 marks.

But for this story I'll leave the telling to my friend Herbert Schaefer, who worked some sixty hours per week on that project.

The man-carrying rocket, called the "Pilot Rocket," was to be a huge monster about 25 feet high with a rocket motor of 600 kilograms (1300 pounds) thrust. The passenger cabin and the fuel tanks were to be one unit, shaped like a huge artillery shell, while the other unit, comprising the rocket motor and the para-

chute, was a smaller "shell" topping the bigger one. The rocket was supposed to reach an altitude of one kilometer (1100 yards) at which point the parachute was to be ejected while the passenger—he was not a "pilot" since he did not do anything—was to jump out with his own parachute.

A smaller rocket of the same shape was to be built first; except for size it differed from the large one by having its parachute where the large one would have the passenger. This rocket was 15 feet high and equipped with a rocket motor of 200 kilograms (440 pounds) thrust.

We all began to work feverishly although we knew that it would be impossible to get such rockets ready in the time interval agreed upon. But it meant an opportunity to build large rockets without being handicapped by lack of funds. The actual work began around Christmas 1932, 440-pound thrust motors were designed and built, and also a new test stand was designed to "take" 1000-kilogram (2200-pound) rockets. That stand was ready in March 1933, but one of the new motors was ready earlier and was tested on a provisional test stand on March 9.

It could be heard for miles. The big new stand actually worked for the first time on March 22. It worked to our full satisfaction. Three days later one of the motors exploded at the instant of ignition; the concussion was so bad that the eyeballs of the observers pained considerably. We had expected some such mishap and had eight such motors scheduled. For a week I spent all my time in the welding shop supervising the construction of them. The second motor exploded, also on ignition, on April 3. This was the last real explosion, but on three successive tests the exhaust nozzles burned through at the throat (the narrowest part). Some twenty test runs were made in April; the thrusts obtained varied between 150 and 200 kilograms, depending on the fuel-oxygen ratios. Finally we considered that type of motor reliable.

The City of Magdeburg hurried us and it was agreed to let the big rocket (but not the man-carrying) ascend on June 9. A large launching rack was built in a cow pasture at Wolmirstedt near Magdeburg. It was 30 feet high. Then a series of mishaps began. The rocket could not be attended properly so far away from the workshops. On the morning of June 9 it was fired, the rocket began to rise slowly, but before she reached the top of the rack she began to slide down again, very slowly. The thrust was insufficient and the reason could not be found. Another attempt two days later was spoiled by a leaky gasket. The motor got only

one quarter of the fuel it was supposed to get, the rocket roared for two minutes instead of 30 seconds, and we approached to within 10 feet. Of course the rocket did not move. Another test on June 13 also ended prematurely. When the rocket was 6 feet high a vent screw popped out and the rocket fell back, getting no more fuel.

We decided on a complete overhaul. After that new tests with all kinds of little mishaps; once a valve froze tight, another time the ignition capsule was blown out before it ignited the rocket, a diaphragm in the fuel line burst, etc. Heavy rains interfered and warped the wooden launching rack, not enough to be noticed, unfortunately. The city accountants had not granted the expenditure of a metal rack. Thus, when the rocket finally did take off on June 29, one of the rollers derailed and became stuck. The rocket just stripped it but took off almost horizontally because of that. Losing altitude rapidly, the rocket made a belly landing 1000 feet from the rack, the motor still going full blast. It slithered for another 30 feet. It looked totally smashed, but the motor and the tanks were unhurt. Only the casing, fuel lines, etc., had been smashed.

This was the Magdeburg Project itself. It had an aftermath which is still of interest. Schaefer's shorthand notes describe it as follows:

We decided not to wait for another casing but converted the motor and the tanks into a four-stick-repulsor, 7.5 feet high. This repulsor was tested on "Lover's Island" (official name on maps is Lindwerder) in Tegeler Lake near Berlin. She rose with terrific velocity to about 3000 feet, suddenly tilted over up there, made a few loops, and came down in a power dive, landing some 300 feet from the island in the water. The parachute was ejected at the last moment before striking, thus only minor damage was sustained. Another repulsor, with minor modifications, was tested from same island on July 21. The first try was unsuccessful; the valve burst, but after replacement and refueling the repulsor took off. One oxygen valve failed to open, and the repulsor rose slowly and off balance to about 200 feet. It landed in water with only minor damage.

The captain who owned "Lover's Island" objected—we scared his summer campers. We went to Schwielow Lake, using a motor launch instead of an island. Same type of repulsors. Test on Saturday, August 5, 1933. Exploded soon after take-off. Next test same type repulsor, same place, August 11. Seems that one valve did not open, horizontal flight, touching water. Sank in steam-

boat channel, the only dredged and deep section of the whole shallow lake. Rescue impossible. August 31, same type, same place. Flew away, could not be found again.

September 9 and 18. Two tests with new design, two-sticker with very long tanks and 200-kilogram motor. Same place. Both poor.

And another one of Schaefer's shorthand notes:

Nebel had hoped that by stringing along with a uniformed organization he could achieve something. All he achieved was that they "took over"; the sound of marching boots became common on the proving grounds and we were asked to join the organization (I and some others refused which caused a lot of friction). A young man with high boots, a blue uniform, and an arrogant bearing became some sort of an overseer. Most of us looked right through him.

Finally the Gestapo seized the journals, papers, books, and all the records—probably the equipment too. The men who worked at the *Raketenflugplatz* were given jobs, mostly in industrial firms like Siemens. I left Germany during the very first days of the year 1935, coming to the United States via England and unwittingly following the same route Fritz Lang had taken when he quietly vanished overnight after Goebbels had offered to make him "Führer of the German Film Industry."

Some three months later a daring editor wrote me that the press had been forbidden to even mention the word "rocket," no matter in what connection. Four weeks after that somebody overheard somebody else's telephone conversation with the War Ministry. It contained the sentence: "Now I've all the rocket people safely on ice around here and can watch what they're doing."

In 1936 Schaefer joined me in New York.

Chapter 7:

THE METEOROLOGICAL ROCKET

In order to go higher, and man will want to go higher, it will be necessary to adopt a different principle. The principle of the rocket is indicated which will lead to a reaction motor.—Capitaine F. Ferber (de Rue) (1911).

THE question is justified now: Why were all these experiments made?

It is a simple question, but the answer is not so easy. It would have differed somewhat with the individual of whom it was asked. And it would also have depended on the time when it was asked. In general and for the first two years of experimentation the answer would have been that we regarded our repulsors as "infant spaceships," as first small-scale models that were supposed to grow into man-carrying, space-spanning craft.

The first impulse would have been to say that we were interested in the intermediate stages only from the point of view of whether they worked or not. But in broad outline the answer had been given by Count von Pirquet in my book *Die Möglichkeit der Weltraumfahrt* even before the first experiment was made. The logical sequence of development, both technologically speaking and with a view to financial self-support of the research work, was a subdivision into three successive steps which von Pirquet called the "Registering Rocket," the "Long-Distance Rocket," and the "Space Rocket."

He had pointed out that it did not matter if research should fail to proceed for some time after any one of these steps had been realized, since each would be an accomplishment in itself and would presumably pay its way. Simultaneously von Pirquet had made it very clear that a rocket would be totally unsuited as a prime mover for wheeled vehicles of any type—the Opel experiments were made just in time to prove him right. It also could not be a prime mover for aircraft, at least not in the sense of replacing the customary engine-propeller combination for existing types of

airplanes—which was what Valier advocated loudly in many gaudily illustrated magazine articles. Whether the development of special types of aircraft for rocket propulsion was a possibility could not be judged then. For a while it appeared rather doubtful.

It was clear, therefore, that the best way to use a rocket is to use it as a rocket and that a rocket would find its maximum usefulness in the literally limitless space which is beyond the reach of anything else. And while some, especially Nebel and von Braun, felt like disregarding von Pirquet's "Registering Rocket" in favor of the "Long-Distance Rocket" (for military purposes), the actual work had progressed in the direction of Pirquet's first step, usually called the "meteorological rocket."

Essentially it is a repulsor, returning by parachute, which carries a set of self-registering meteorological instruments of more or less, but probably more, customary type and design.

The idea is not new by any means. Dr. Goddard clearly had this purpose in mind all along and Oberth devoted a good portion of his first book to the description of such a proposed rocket which he called *Model B*. Farther back, in the days before the First World War, the United States Patent Office even granted a patent on an "instrument-carrying rocket" (powder rocket).¹ And meteorologists have repeatedly stated the need for such a device and their desire to see it developed.² The science of meteorology relies on the knowledge of conditions in the upper atmosphere. And navigation and aviation, and to a large extent agriculture too, rely, in turn, on meteorology.

It can be said without reservation that meteorologists have always been quick to see how their own science can be benefited by new inventions. The very first hydrogen balloon that took to the air, on December 1, 1783, carried a barometer and a thermometer. One year later, almost to the day (on November 30, 1784), followed the first balloon ascent specifically devoted to meteorological research. That vertical expedition had been fathered by an American, Dr. John Jeffries of Boston, who then resided in London.

¹ U.S. patent No. 847,198, granted to Alfred Maul of Dresden on March 12, 1907.

² For example, Gordon M. B. Dobson of Oxford University, in his "Halley Lecture" of May 5, 1926.

He carried six bottles filled with distilled water along with him; they were emptied at various heights and sealed. The samples of air thus obtained were analyzed later. Along with these six bottles the gondola was cluttered with a thermometer, a barometer, a hygrometer, an electroscope, and a mariner's compass.

Other such vertical expeditions followed, and in some cases the balloons went so high that the lives of the men in the gondola were seriously endangered. But in spite of this danger it took almost a full century until somebody conceived the idea that such research work might well be done by means of small and unmanned balloons, carrying automatic self-recording instruments. The earliest suggestion of this kind seems to have been made by Brissonet in 1879. Brissonet's suggestion was fine; it had only one drawback—self-registering and sufficiently light meteorological instruments did not exist then. This was still true a few years later when the German meteorologist Assmann made the same suggestion.

Assmann then drew the conclusion that such instruments should be developed if they did not exist and began doing so in 1891. At the same time two Frenchmen, Gustave Hermite and Georges Besançon, had drawn the same conclusion from the answers Brissonet's suggestion had evoked, and they began designing and building the same tiny instruments over which Assmann was sweating. They won the race; on March 21, 1893, the first *ballon sonde* or sounding balloon was released in France. It reached an altitude of 15,000 meters or about 49,200 feet. A German sounding balloon, released on April 27, 1894, reached 21,800 meters or 71,500 feet. Assmann and his associates had the satisfaction of having gone higher, even if they had lost the glory of being the first. This is about the same altitude as that attained many years later by manned stratosphere balloons, the American *Explorer II* and the Russian *Stratostat*. (The latter does not count officially because it did not land safely.) In the interim sounding balloons had broken their own early records again and again, and at present the altitude record for a sounding balloon belongs to one that was released near Hamburg on September 8, 1930. It attained 35,900 meters or 117,750 feet (22.4 miles). (There exist several slightly higher claims for other sounding balloons but they are, as far as I know, not officially recognized.)

These instrument-carrying balloons have gathered a great many

useful data (see Appendix 2). They have, among other things, taught us that the atmosphere has several distinct layers. The one nearest the surface is known to meteorologists and aviators as the Troposphere. This is the turbulent layer with cloud formations, vertical currents, and "weather." It is characterized by steadily decreasing density and temperature the higher the altitude. At sea level air pressure averages 760 millimeters or 29.92 inches of mercury. At 11 kilometers (about 6.8 miles or 36,000 feet), which is the approximate upper limit of the troposphere, the pressure is only 165 millimeters or a little over 6½ inches.

Higher up, at 15 kilometers or about 9.4 miles, the pressure is only a little over 3½ inches or 90 millimeters. This means that the volume of a cubic foot contains only 11.7 per cent of the air which can be found in a cubic foot at sea level. The corresponding figure for an altitude of 11 kilometers is 22 per cent. But the composition of the thinner air at 11 kilometers differs from that of the dense air near sea level in only one respect: all water vapor has disappeared and oxygen and nitrogen have gained correspondingly.

During the first 11 kilometers the temperature falls off at the rate of about 1 degree Fahrenheit per 300 feet of ascent, or 6 degrees Centigrade per kilometer. It reaches a low of minus 55 degrees Centigrade or minus 67 degrees Fahrenheit. From then on it remains the same and even has a slight tendency to rise. This means that we have now entered another layer where only the density continues to fall off, but no longer the temperature. This less turbulent and therefore more "stratified" layer is known as the Stratosphere, and the imaginary dividing line or rather dividing shell between the troposphere and the stratosphere goes under the name of Tropopause. The tropopause, generally said to be at about 11 kilometers or 7 miles (it varies from 9-19 kilometers with latitude and season), is not a layer in itself but only the dividing line.

We know very little about the higher stratosphere, simply because it has not yet been possible to take any direct measurements high above the tropopause. For these higher layers meteorologists have to depend on indirect observations which are often enough chance observations:

After the sun sets, light is still reflected toward the earth by the higher layers of the atmosphere. Calculation has shown that the highest layers capable of diffusing sunlight occur at about 60

kilometers. Luminous or pearl clouds, whose altitudes have been definitely established by triangulation, have been observed at night at altitudes of 80 kilometers. Shooting stars appear at about 300 kilometers. . . . The Aurora Borealis have a maximum frequency at about 100 kilometers, while some rays reach to altitudes of 1000 kilometers. The study of the propagation of radio waves has led to the conclusion that an ionized zone called the Heaviside Layer exists at an elevation of more than 80 kilometers.³

All these facts taken together permit the conclusion that the atmosphere has a total height of about 400 kilometers while a highly attenuated outer shell—if we had made it in the laboratory we'd call it a hard vacuum—reaches to about 1000 kilometers. But that is about all that can be said with any degree of certainty. Any figures for the density of the air at, say, 200 kilometers which you may find in scientific literature will differ with each other to an enormous extent. The reason is simple. To calculate the density we should know the temperature and the amount of hydrogen gas present. As for the temperature: we don't know. As for the amount of hydrogen: it is certainly small, but nobody can say whether it is one part in a hundred thousand or one part in a hundred million, and the result of the calculation will differ greatly depending on whether the one or the other value is used.

But the conditions in higher layers of the atmosphere are not only worth knowing for the sake of knowledge, they are of great practical importance. Aviation is forging higher and higher, but if you want to fly safely at 40,000 feet you should know conditions well up to 60,000 feet. And if later rocket airplanes want to go up to 60,000 feet it would be useful to have a good picture of conditions up to 100,000 feet.

The balloon *Explorer II* reached an altitude of 72,395 feet on November 11, 1935, and remained at its ceiling for one hour and a half. It was the biggest and most expensive balloon ever built and it carried a full ton of scientific equipment. When at the ceiling, the men in the spherical gondola had 24/25 of the total mass of the earth's atmosphere under their feet and the sky, of a normal blue near the horizon, looked darkish near the zenith. The zenith

³ *Weather Manual for Pilots* (War Department, May 27, 1940), Technical Manual TM 1-230.

itself was presumably black, but could not be observed because of the gas bag.

Outside of the spherical gondola a small propeller was mounted at the end of a long strut. The gondola was painted white on one side and black on the other, and the propeller was to turn gondola and balloon around so that either the white or the black side were exposed to the sun, depending on whether it was too warm or too cold in the gondola. At peak altitude the propeller worked with 5000 revolutions per minute, but it had no noticeable effect. The air was too thin for propellers!

The balloon *Explorer II* brought very valuable data back to the ground and the flight was a great success in every respect. But stratosphere research cannot depend entirely on balloon flights of this kind. Such balloons are of enormous size and need a very large ground crew to handle them. They are too expensive in themselves too, especially since the bag cannot be expected to last for more than one flight.

Sounding balloons are inexpensive, but that does not mean that they are ideal. The bag of a sounding balloon consists of rubber and the lifting hydrogen or helium inside keeps expanding the bag at a rate equal to the drop of outside pressure. This goes on until the bag bursts; the instruments then return by parachute. It sounds like a neat trick, but it has its drawbacks. The balloon may drift for a long time until it bursts and the instruments returning by parachute experience another drift, although of shorter duration. Consequently the ratio of instrument losses is high, so high that it is useless to release balloons on days with zero visibility.

More important than the high ratio of losses and the interruptions of series of data because of "grounding" in zero visibility is the fact that sounding balloons rarely ascend to the normal ceiling of aircraft equipped with superchargers. Those records of 70,000 and 100,000 feet are very definitely records far above the average performance. Not even 30,000 feet can be counted on every time.

The meteorological rocket will be able to take over from that point on, carrying instruments to any desired altitude in any kind of weather without an important amount of drift during the ascent.

A meteorological rocket able to duplicate the feats of the most successful sounding balloons can be achieved in the near future. The One-Stick Repulsors of the VfR were the prototype, and it would take no more than two years of intensive work to make the

meteorological rocket a reality. (Fig. 30.) It is so close to reality that it can be described even now.⁴

The rocket, looking almost precisely like a One-Stick Repulsor, would be of the nose-drive type, i. e., the rocket motor would be located on top in a fork formed of fuel lines and struts and would pull the rocket. The whole rocket would weigh 20 kilograms (44 pounds) when ready for the take-off. Of this total weight half goes for liquid oxygen and fuel, 1 kilogram is the allowance made for the instruments, while the rocket with parachute weighs 9 kilograms. Its total height, not counting the "fork" and the rocket motor at its end, would be close to 3 meters or about 10 feet.

To begin with the motor: it would have to deliver a thrust of 60 kilograms (132 pounds) and develop an exhaust velocity of 2500 meters per second. Burning 236 grams of fuel and oxygen per second, it would use up the whole available supply of 10 kilograms in 42.5 seconds. The material for the motor would be aluminum or another metal characterized by a high heat conductivity factor. It would be water-cooled or fuel-cooled in the manner employed by Dr. Sanger.

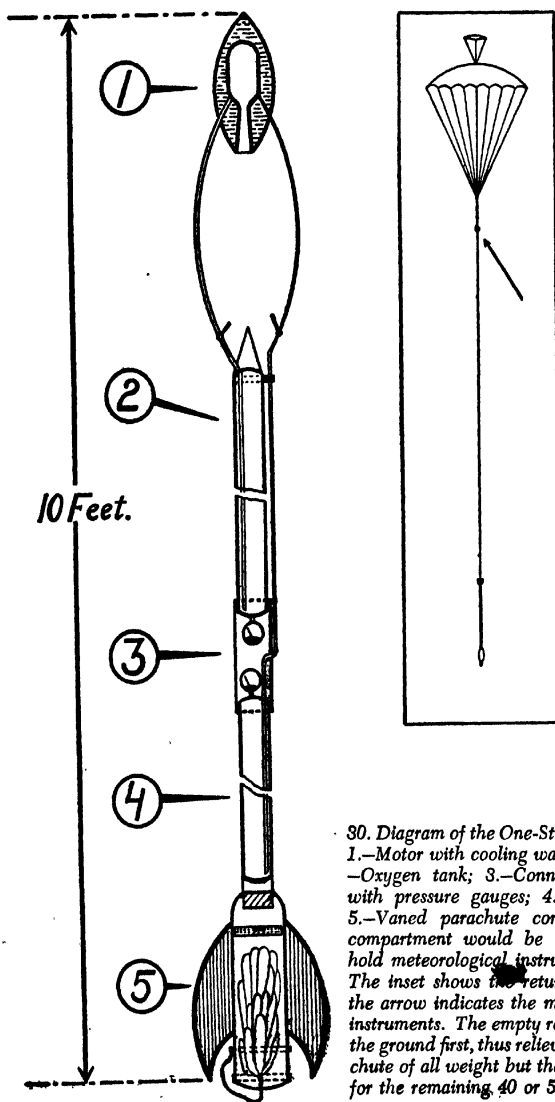
Air-cooled, or rather uncooled, motors are unlikely to stand up for that length of time. I remember that Krupp engineers, visiting the *Raketenflugplatz*, told long stories about a marvellous new steel for safety deposit boxes which had been developed by their firm. They claimed that it was virtually burglar-proof, not because it would not yield to a cutting torch in the end, but because cutting it would take so long and require so much oxygen that a burglar could not carry the necessary amount. They later mailed us a sample of that steel, a sheet of the proper thickness which we soon made into a rocket motor of the "standard" type.

It looked a sinister dull grey when it was screwed to the test stand. It still looked dull grey a second after the beginning of the test run. Then it turned dull red, grew a bright cherry red, and a split second later the experiment ended in a beautiful display of bright sparks.

As I said before, the motor would have to be water- or fuel-cooled.

The tanks of the meteorological rocket would consist of seam-

⁴ This description is based on two articles by Ley and Schaefer: "Les Fusées volantes météorologiques" in *l'Aérophile* (Paris, October 1936), and "Meteorological Research by Means of High Altitude Rockets" in *The Military Engineer* (Washington D. C., November 1943).



30. Diagram of the One-Stick Repulsor.

1.—Motor with cooling water-jacket; 2.—Oxygen tank; 3.—Connecting piece with pressure gauges; 4.—Fuel tank; 5.—Vaned parachute container. This compartment would be elongated to hold meteorological instruments.

The inset shows the returning rocket; the arrow indicates the meteorological instruments. The empty rocket touches the ground first, thus relieving the parachute of all weight but the instruments for the remaining 40 or 50 feet.

less tubing of light metal alloys. A lightly coppered magnesium alloy would be preferable because of its lesser specific weight, but the better grades of aluminum alloys (for example, the type 17 ST) could be used just as well, since the weight margin is not as narrow as is believed by a number of rocket enthusiasts. The outside diameter of the tanks would be 100 millimeters or about 4 inches; their inside diameter would depend on the material used. The tanks should be able to stand an internal pressure of around 550 pounds per square inch.

The total length of both tanks together would be 2500 millimeters or about 100 inches which allows for "empty" space above the fuel and oxygen levels. How the tank length is divided between the fuel tank and the oxygen tank (the latter would be on top) would depend upon the fuel used.

There are no "secret" rocket fuels. Anything that is liquid and will burn can be used. The question is merely which one will perform best and is most advantageous all around. Benzene, for example, while excellent in many respects, is barred because its freezing point is too high, and freezing, because of the vicinity of the super-cold liquid oxygen, is a factor to be considered. Other hydrocarbons which might be good are barred because they are either too expensive or not readily available or both. Liquid methane is an excellent fuel, but I am opposed to it because I have discovered that one liquefied gas is enough trouble. Why bother with two?

The best and cheapest fuels are simply gasoline and alcohol. The advantage of gasoline is that it is even more readily available than alcohol; the advantage of alcohol is that it is chemically uniform. It has the further advantage of requiring less liquid oxygen; the ratio of oxygen to alcohol for complete combustion is 2.08 to 1, while for gasoline it is 3.5 to 1 (the "1" represents the fuel in both cases). The length ratio between fuel tank and oxygen tank would correspond with the weight ratio for complete combustion, but the choice of fuel would not affect the total length of both tanks taken together.

Below the fuel tank, tubular space of the same diameter would be provided for the steering mechanism, the instruments to be carried, and, finally, for the parachute and its release mechanism. The total length of this space would be 500 millimeters or about 20 inches—5 or 6 inches more would be nothing to worry about.

There is little to be said about the parachute and its release mechanism. Whether a steering mechanism will be required or not cannot be decided without full-scale experiments; so far it looks as if there is a good chance that the rocket can do without it.

If it is needed, it would be a small gyroscopic instrument that produces the proper movement of steering vanes which prevent the rocket from veering off the vertical path. The type of instrument required exists, but only in an application for airplanes. The existing type would, of course, be much too heavy for a rocket. It also would be—which may seem strange—too accurate. The existing variety or varieties are useless for this purpose. But instrument designers feel confident that the design of a small and light mechanism of that type will not present any great problems. The job is simplified by the fact that such a mechanism will not have to run for more than a few minutes at a time and that it will not have to do more than prevent deviations of more than 5 degrees from the vertical.

But, as I said, it looks as if it can be done without such an instrument which, although it would not be a very difficult problem, would increase the cost of such rockets.

In order to find out how such a rocket would perform it was necessary to calculate the theoretical performances of a number of rockets. The method of calculation and tables of the final results are given in Appendix 2, but the problem itself can be explained at this point.

The rocket, at the moment of the take-off, weighs 44 pounds. If the rocket motor developed a thrust of only 44 pounds, nothing would happen at first. But then the rocket would begin to grow lighter because of the steady fuel consumption, while the thrust of the rocket motor would remain the same. The rocket would begin to rise slowly, gathering speed, until the fuel supply was exhausted. At that instant it would attain the highest velocity of its ascent and would continue until its kinetic energy has been eaten up by the action of gravity and by air resistance.

We'll now assume that the rocket motor has a thrust of 88 pounds, twice the weight of the fully loaded rocket. Then the rocket would ascend with an acceleration of 32 feet per second for every second elapsed. It would be like a fall in reverse on general principles, but with a few minor modifications.

These modifications are, I hasten to add, minor only in this par-

ticular example. It is easy to imagine cases where they would become major modifications.

The modifications are these: It would be a reversed fall if the rocket motor had a thrust of precisely twice the weight of the rocket at any instant during the ascent. Since the weight of the rocket goes down as fuel is consumed, the thrust of the motor should go down too to fulfill this condition. But the thrust remains practically the same throughout the burning time. Because of this not only does the speed of the rocket mount, the acceleration increases also. In other words, the rocket does better than merely demonstrate a reversed fall. But now another complication sets in: air resistance. It gets worse the higher the speed becomes.

The initial acceleration of a rocket is expressed in terms of g . The rocket of the first example which has only as much thrust as it weighs itself—and which begins to rise only when it weighs less—has an acceleration of $1g$. That $1g$ is spent fighting gravity and therefore does not count really. The second rocket, with a thrust of twice its weight, has an acceleration of $2g$ or, since one of them is counteracted by gravity, of $1g$ effective. It has become customary to talk only of the effective acceleration. If you wanted to be strict, you'd have to say that a given rocket has an acceleration of $5g$ or $4g$ effective. But it is simply called a $4g$ rocket.

The rocket designer now finds himself in the following dilemma. (We'll assume that he has no trouble building a rocket with as many g as he likes.) If he builds a $1g$ rocket, everything is nice and moderate. The acceleration is $1g$ in the beginning and goes up slowly to around $2g$ for the last few seconds of burning. The velocity mounts accordingly, never reaching very high values and, therefore, never causing any excessive air resistance. But such a low-acceleration rocket is apt to be unstable in air. It might require a stabilizing gyro-instrument.

So the designer goes to the other extreme. He builds a rocket with $10g$. It accelerates like mad and produces proportionate velocities. Or rather, it wants to, but fails because the air resistance very quickly goes up to such a value that the rocket spends most of its energy fighting air resistance instead of climbing.

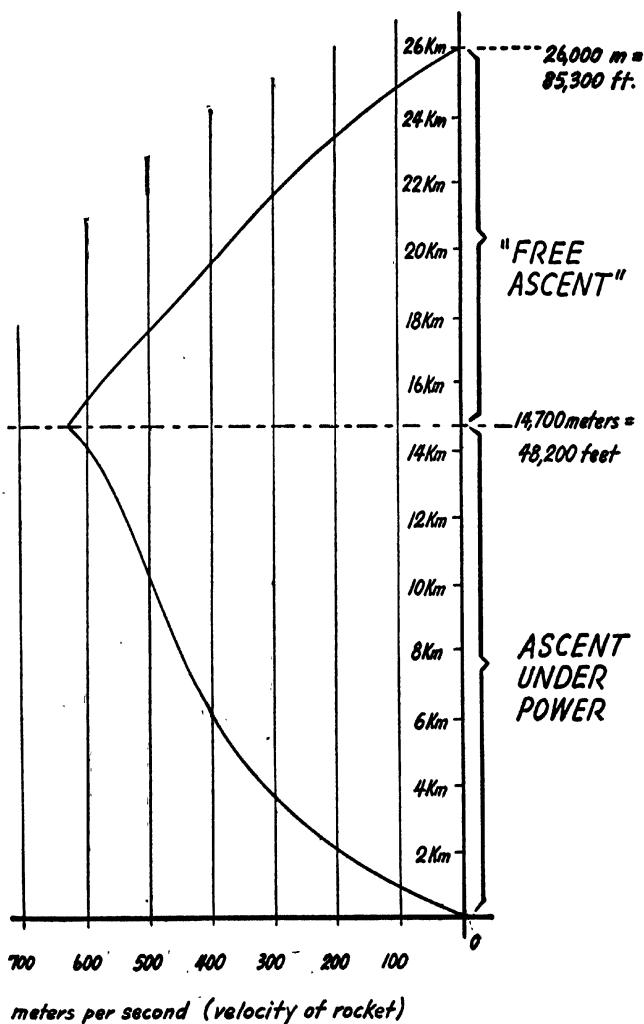
At this point I am pleased to introduce two more complications, both of which, for a change, are favorable. One of them is that gravitational attraction falls off at great heights. But this is not much comfort in reality, because the heights where this begins to

help are immense; it doesn't begin to show until after the first 600 miles. The other complication, which is a comfort, is that the density of the atmosphere, and hence the air resistance, falls off too. And that shows very soon; it begins to be really helpful after the first 6 miles. Clearly, then, a rocket should accelerate fairly slowly so that the velocities do not become high until above the 6-mile level. In this way the rocket will spend more time fighting gravity, it is true, but it will not fight unnecessary air resistance, which happens to be a more important factor in meteorological rockets.

The problem is now to find an acceleration where the air resistance encountered stays within reasonable limits but which is high enough to make the rocket stable without a special stabilizer. There is no definite theoretical answer to that problem. Schaefer and I are inclined to believe that even a 1g rocket might be able to do without a stabilizer. It is not quite certain, but it is very likely. For a 2g rocket, the type I have been describing all the time, it may safely be assumed. Fig. 31 shows its velocity diagram.

It can be seen that the velocity goes up fairly rapidly until it passes the mark of 300 meters or about 1000 feet per second, which is about the speed of sound in air. Then, although the velocity continues to increase, the rate of increase falls off. Only near the end, when the rocket is above 30,000 feet, does the velocity increase again at a greater rate. There are two reasons for this. One is that the rocket is now very light, having used up most of its fuel. The thrust is now relatively higher, and the rocket acts like a rocket with higher acceleration which, of course, is the case. The other reason is that the density of the air has decreased greatly at that altitude, and the air resistance is less even at higher speeds. The top speed of this particular rocket is roughly twice the speed of sound. It is attained at the instant the fuel supply gives out, which takes place after 42.5 seconds at an altitude of 14,700 meters or 48,200 feet.

Now, with the rocket motor silent, air resistance and gravity can really go to work. With combined efforts they manage to kill the speed of the rocket in a little over another minute or so. The rocket, of course, keeps climbing until the speed becomes zero. This takes place at an altitude of 26,000 meters or 85,300 feet, roughly 10,000 feet above the peak of *Explorer II*. Then it begins to fall back.



31. Speed Diagram of a Meteorological Rocket.

The curve shows the speed of the rocket at any moment during its ascent under power until the supply of fuels is exhausted. This point lies at 48,200 feet, but the rocket at that moment has a speed of about 620 meters per second (1985 feet per second) which is sufficient to carry it upward for another 37,000 feet to a total altitude of 85,300 feet.

The curve shown in Fig. 31 is based on calculation, but the actual curve will be very much like this calculated curve. And such a rocket can be built.

But there are a few things to be added here before we go on. The curve for the 1g rocket shows a higher altitude (almost 31,000 meters), but it might need a stabilizer. The curve for the 4g rocket, which was also computed for comparison, shows a peak altitude of only 20,600 meters; that rocket is too fast too early and spends too much energy fighting air resistance.

On an airless planet, say when taking off from the moon, the rocket with the highest acceleration would go the highest, since it spends less time fighting gravity. But in our atmosphere the fight against air resistance is much more important than the fight against gravity.

However, there is a way of avoiding the most troublesome layer of the atmosphere. It consists in letting the rocket take off from the top of a high mountain, where air density is less. Just to find out what would happen, the 2g rocket described was calculated to take off from two mountains, one 4000 and the other 5000 meters high (about 13,000 and 16,000 feet). From the top of the 4000-meter mountain the rocket attained 43,400 meters, instead of 26,000 + 4000 meters—a clear gain of more than 13,000 meters, accomplished by moving through rarefied air from the outset. From the top of the 5000-meter mountain the rocket attained 48,700 meters, a gain of close to 18,000 meters because it was still more rarefied air.

After that question had been settled, another question had to be investigated. What would happen if the instruments turned out to be rather heavy, if a stabilizer should be needed even for the 2g rocket, and if the whole construction turned out to be much heavier than (by comparison) the One-Stick Repulsors of the VjR?

It was assumed that the rocket would weigh 46 kilograms when fully fueled, not only 20 kilograms as in the first example. Of the 46 kilograms 20 kilograms were assigned as the dead weight, the other 26 kilograms being fuels. The rocket was assumed to have the same proportions as the first one, but thicker and larger all around.

The heavier 2g rocket was found to attain a peak altitude of 27,300 meters instead of 26,000 meters. That proved that a greater weight would not matter very much if necessary. Each ascent would cost only 2.6 times as much in fuel, not an important amount in dollars and cents.

But something else was proved by that calculation. The lighter 2g rocket attained 14,700 meters under power and coasted upward for another 11,300 meters. The heavier 2g rocket attained 12,800 meters under power, 1900 meters less than the first. But the heavier rocket then managed to ascend another 14,500 meters without power, 3200 meters more than the lighter one. In other words, what it lost under powered ascent it more than made up under free ascent. The heavier rocket, due to its greater weight, had more penetration than the lighter one.

This is the reason why, as I said before, the weight margins do not have to be watched as carefully as, for example, Winkler did.

As regards the instruments, it is unlikely that they will be responsible for a greater weight. Instrument builders have performed great feats since the days of Assmann, Besançon, and Hermite. They have, in particular, succeeded in eliminating a good deal of the annoyance caused by the high loss in equipment. This has been done by incorporating a small short-wave radio sender which relays the data to a station on the ground as the instruments register them. By that means the data will go on record even though the instruments themselves may be lost.

In the calculations the allowance made for weight of the instruments was 1 kilogram or 2.2 lbs which is only about 2 ounces less than they actually weigh. But since weight is not so important within small limits, it would be possible to carry additional instruments, for example an air sampler and a spore collector.

The main advantages of the meteorological rocket, when compared with a sounding balloon, are:

(1) The rocket can regularly attain the highest record altitudes of sounding balloons.

What is more important even than the high altitude, however, is the reliability of rocket ascents. An instrument-carrying rocket designed for, say, 60,000 feet will always rise to 60,000 feet with only a small margin of error, while there is no way of telling how high any specific balloon will go.

(2) It has less drift because of the rapid ascent, between one minute and ninety seconds for those altitudes normally reached by sounding balloons, while the sounding balloon requires between two and two and a half hours, rising at best only 200 meters per minute.

(3) The parachute drift of the rocket will be smaller too since

the rocket descends somewhat faster than the instruments of a sounding balloon. The instruments of the rocket are, however, less apt to suffer damage because they are still some 30 feet or more above the ground when the rocket itself touches ground and relieves the parachute of its weight. The instruments would sink down very slowly during these remaining 30 feet.

(4) The batteries and the radio transmitter can be used to broadcast a monotone (using the rocket as an aerial) for as long as the batteries last (a period of several hours) after the mission is completed. This monotone will facilitate finding the rocket by means of triangulation.

To these advantages a few more may be added which are likely to prove rather valuable in routine handling. It is exceedingly difficult to get a balloon off the ground in a high wind which will seize it and carry it off immediately. And a balloon which could well reach 40,000 or 45,000 feet will be unable to go beyond 10,000 or 12,000 feet if icing conditions are encountered in those altitudes. Rockets, of course, would not be influenced much by a high wind and not at all by icing conditions.

The meteorological rocket can be realized soon. I know that after all this I will be expected to make an estimate of some kind and, although I am reluctant to do so, I don't want to disappoint this expectation. It is my estimate that the realization of the meteorological rocket, as described, will require an expenditure of around \$2000-\$3000 per month for a period of not less than two but not more than three years. (No overhead included.)

The meteorological rocket, the first goal of scientific rocket research, is definitely in view, thanks mainly to the work done many years ago on the proving ground of the *VfR*. But the theory goes further. The theory says (and proves, as far as it is possible mathematically) that the space rocket, the rocket which ascends beyond the last traces of the atmosphere, will come after the meteorological rocket. The theory says too that the famous, much discussed and also much ridiculed "rocket to the moon" is possible too.

And I wish to affirm with great seriousness that the rocket to the moon is possible. Whether it has any practical value is another question and whether the experiment will actually be made is still another story. But these "higher" rockets are as possible as the meteorological rocket.

They are only further in the future.

Chapter 8:

THE ROCKETS OF THE SECOND WORLD WAR

*In Stahl gehüllt
vom Strahl umwittert
die Schar, die Reich um Reich zerbrach
sie treten auf,
die Erde schüttert
sie schreiten fort, es donnert nach!*
—Goethe (Faust, II)

IN 1942 the first pictures of a strange-looking German weapon began to appear in pictorial magazines and in the daily press. The device had six fairly stubby barrels, arranged in a circle very much like the round cartridge chamber of the old Colt revolver. The undercarriage, as could easily be seen in the photographs, was that of a German 37-millimeter anti-tank gun, with only minor modifications.

The stories that came with the photographs, which had been taken along the battlefronts in Russia, stated that this strange-looking object was a German rocket gun. The name given was *Nebelwerfer 41* which means "Fog (or Smoke) Thrower Model 1941." That name indicated that the weapon had been originally intended as a type of chemical mortar, presumably for laying smoke screens. But when it was used by the Germans it was used like a howitzer and fired shells which could be compared to ordinary artillery ammunition rather than to chemical projectiles.

The firing tubes were open at both ends, but a finger-like projection in the rear prevented the rockets from sliding out when the tubes were elevated. Inside the tubes there were three straight guide rails, about $\frac{1}{8}$ inch deep. The rocket shells were ignited electrically; the fastest rate of fire observed by the Russians was the discharge of all six barrels in as many seconds. The rocket shells were almost as long as the launching tubes and weighed 25 kilograms or about 55 pounds each. Their caliber was 15 centimeters or about 6 inches. The range was observed to be from 6000 to 7000 yards, the accuracy of fire was fair but, of course, much inferior to artillery under similar conditions.

But its main drawback was not the lack of accuracy, which could be compensated for by large volume of fire. The main drawback was that it was virtually impossible to fire this weapon without being detected, especially at night. The flash of the rocket charge, jetting out through the open tail end of the firing tube, was 20 yards long and brilliantly bright. The *Nebelwerfer* could be camouflaged while being transported and it could be hidden when in position, but it could not be operated without giving itself away in an unmistakable manner. This was true even in daytime. The flash was not so conspicuous, but the back blast of the rockets kicked up large clouds of dust.

It was not difficult to trace the history of this particular weapon. Potentially it had been a part of the German arsenal since 1910, but for unknown reasons (one may guess at certain difficulties of manufacture) it had not been used during the First World War and had not been developed and manufactured until the Second World War was well under way.

The original inventor of the *Nebelwerfer* is probably the Swedish Baron von Unge.

Lieutenant-Colonel von Unge spoke about his aerial torpedoes for the first time in 1900. He advocated rocket-propelled shells patterned after the stickless war rockets of William Hale. To increase the range of these projectiles, von Unge advocated firing them from a short howitzer with a muzzle velocity of only about 300 feet per second. Such a slight muzzle velocity, he reasoned, would give considerable ballistic advantages without necessitating too sturdy a construction of the rocket itself. The idea was not quite new since a similar method had been used occasionally in pyrotechnic displays for amusement purposes. Sky rockets launched in that manner seemed to originate from a point in midair since the "ballistic ascent" naturally could not be seen at night.

In 1901 a corporation with the name of "Mars" was founded in Stockholm to develop von Unge's principles. The results of these experiments were never published, but some facts became known later on in a roundabout manner. The propelling charge was the same in composition and method of manufacture as that of the line-throwing rocket used by coastal lifesaving units. It was a black powder mixture with an excess of coal, hammered into the rocket tube by hand. The shell was attached to the top of the rocket tube. Its charge consisted of dynamite, and the fuze was of

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the percussion type, set off by striking the target. Nitrogelatin was also tried, as were time fuzes which were ignited by the propelling charge.

The weight of the high-explosive charge was 2 kilograms (4.4 pounds). The over-all length of the aerial torpedoes was 750 millimeters, the diameter 10 millimeters. The over-all weight of the early models was 35 kilograms, the highest velocity attained along the trajectory was 300 meters per second (about 1000 feet per second), and the extreme range 5 kilometers, not quite 5500 yards. The mortar supplied an initial velocity of 50 meters per second (165 feet per second). This was found to be too small, but the design of the torpedoes apparently did not permit a higher propelling charge in the mortar. The accuracy of fire was admittedly "poor." Experts reportedly estimated that at least five times as much ammunition would be needed to hit a given target over a distance of about 2 miles as for howitzers firing comparable projectiles.

Lieutenant-Colonel von Unge then decided to drop the launching mortar completely and to use open guiding tubes instead. When the two Swedish dirigibles *Svenska I* and *Svenska II* attracted much attention in his homeland, von Unge began to advocate his aerial torpedoes as weapons for aircraft (meaning dirigibles) either against ground targets or for aerial combat. He emphasized that his torpedoes did not produce a recoil, which seemed very important for aircraft armament.

That was in July 1908.

In 1909 it became known that the firm of *Friedrich Krupp, Aktiengesellschaft*, in Essen had purchased the Unge patents and had also bought the existing supply of aerial torpedoes, about a hundred, as well as a launching tube and other equipment. The equipment was transported from Stockholm to Krupp's proving ground at Meppen, and extensive experiments were carried out.

Some information about the latest models has been revealed by Krupp's ballistic expert Prof. Dr. Otto von Eberhard.¹ In the course of a mathematical development of the theory of rocket motion, Dr. von Eberhard stated that von Unge's aerial torpedoes "had a weight of 50 kilograms (110 pounds) and attained a range of from 4000-5000 meters" (about 13,200-16,500 feet).

¹ In his book: *Freier Fall, Wurf und Schuss* (Vol. II of the *Handbuch der physikalischen und technischen Mechanik*), Berlin, 1928.

In 1910, however, Krupp announced that the experimentation with von Unge's invention had been discontinued because it had been found that accuracy of fire could not be achieved.

This announcement was disbelieved, of course, but its truthfulness was borne out by the facts. No weapon which bore any resemblance to von Unge's aerial torpedoes made its appearance during the First World War. Krupp's had probably tried to develop the Unge weapon into short-range heavy artillery and had, after failing to accomplish that, turned its attention to other means of throwing heavy shells over short distances.

It is now perfectly clear why the Germans could not use such a weapon in the First World War and why they, as well as everybody else, could do so in the Second World War. In the meantime an important military invention had been made, an invention which made the mass use of power rockets possible.

The military projectile rocket was beset by an important fuel problem which deserves to be explained in detail.

To begin with, military projectile rockets *had* to be powder rockets. Liquid-fuel rockets, no matter how superior in theory, have one important drawback: they cannot be stored, i.e., they cannot be stored charged and ready for action. A war weapon, however, must be storable. It must be of such a nature that it can be manufactured in large quantities and can then be put away in ammunition stores, that it can be shipped to the theatres of operation and stored again, can be brought up to the front lines and maybe stored once more—but all the time, at least theoretically, a weapon must be ready for instant use. An ordinary cartridge conforms with these demands.

A liquid-fuel rocket does not. While the rocket body, etc., can be stored, while even the projectile which such a rocket would carry for military use could be stored, the fuel would have to travel separately and would have to be put into the rocket immediately before using it. That is something that can be done with a long-range weapon like V-2 of which, furthermore, only one or two are fired at the same time.

But the ordinary military rocket has to be fired in large quantities more or less simultaneously. Since each rocket is not accurate, effectiveness of fire has to be achieved by volume. Liquid-fuel rockets could hardly be used in volume, and it is ridiculous even to imagine that the rocket gunners could fuel their rockets on the field

of battle. By comparison it would be like asking a soldier to assemble his radio set in a foxhole.

Military rockets, therefore, had to be storable powder rockets. But there another problem came up.

The large powder rockets of the period from, say, 1910 to 1935, could not be stored either. Not that it was necessary to put the fuel charge in immediately before use; the fuel charge was there and in position. But that fuel charge did not stand storage or, to be precise, it could stand storage only under very carefully controlled conditions. And it could not stand much handling.

The reason was this: in order to make a powder rocket large and powerful, the powder mixture had to be compressed to a much higher extent than in small fireworks rockets. The specific gravity of the powder in fireworks rockets is about 1.25. The rockets built by Sander for the Opel experiments had a specific gravity of about 1.5 and even 1.7. While that high density improved the performance, it also brought the additional complication that the compressed powder mixture was excessively brittle, much more brittle than customary. If such brittle rockets are subjected to changes of temperature while stored, or if they are transported, fine cracks which cannot possibly be detected are likely to form in the charge. When such a rocket is used, the performance will be normal until the flame reaches the crack. Then the surface of the crack will also become a burning surface, causing a sudden large increase in gas generation. In comparatively harmless cases unburned lumps of composition—those between crack and nozzle—will be thrown out. But usually the tube cannot stand the sudden increase in pressure, which may be aggravated by the blocking of the exhaust nozzle by a still unburned lump of powder.

Such fine cracks caused the explosions that were so frequently observed during the Opel experiments. One sudden drop of temperature, one minor act of carelessness during transportation and handling, and the rocket was unsafe.

It is obvious that such rockets did not meet military demands.

As usual, there was a way out.

As usual, it was very simple in theory and very difficult in practice.

These dangerous and brittle highly compressed rocket charges had old-fashioned blackpowder as a base. If smokeless powder, with a base of guncotton or nitroglycerin, could be used, the charge

would be even more powerful than the most highly condensed blackpowder charge and it would not be brittle. Any ordnance officer knew the spaghetti-like smokeless powder tubes which were used in the propelling charges of artillery shells. These thin and fairly long tubes were not only not brittle, they were actually flexible and could be bent to a considerable extent before breaking.

The problem was to find a smokeless powder composition of just the proper rate of burning—much slower than the rate used in propelling charges for artillery projectiles. Experimentation of this kind must have been going on for years in arsenals all over the world. The appearance of large-size projectile rockets in all warring countries proved that everybody had found a solution to the problem, even though these solutions probably differed from each other.

The American solution consisted of producing a smokeless powder made of a mixture of guncotton, nitroglycerin, and other chemicals. When mixed, they resulted in a thick and viscous blackish paste. This paste, after drying somewhat, was rolled into sheets which were then slit into ribbons of the proper width. Then a special machine squeezed the ribbon into a stick which, in spite of its size, was still called a "grain." Each "grain" was from 3 to 5 feet long and about 4 inches thick. The 5-foot "grain" weighed about 40 pounds. The grains were held in place inside the steel rocket tube by wires.

The most interesting thing about these grains was their shape. They were straight, but neither round nor square, instead their cross-section looked like a plus sign. The ends were fitted with plastic "inhibitors" so that the grains could not burn from the ends but at their surfaces only. Now if the grains had been just solid cylinders or square bars the burning surface, and with it the production of exhaust gases, would have diminished as the powder was consumed. But with a cross-section like a plus sign the burning area remained more or less the same to the last instant of combustion.

Manufacture of these grains was almost fully automatic, and their inspection had to be thorough and rigid since air bubbles in the mixture or accidental holes or flaws would have produced precisely the same result as a crack in a blackpowder rocket.

This digression was necessary to answer the otherwise rather puzzling question why war rockets, which were virtually non-

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existent in the First World War, abounded in the Second. And they did abound. The German *Nebelwerfer* which I used as a starting point because of its long history was, as everybody knows, by no means the only rocket weapon.

Nor was it the first.

In fact the first rocket weapons of the Second World War appeared on the side of the Allies; they were used by the British. When Goering's *Luftwaffe* began to attack England in 1941 it found itself opposed not only by *Spitfires* and *Hurricanes* in the air, but also by massed anti-aircraft fire from the ground. And among the projectiles that rose from the ground there were rockets, launched from a device called *Z-guns*. There were only a few of them at first, but they proved their effectiveness by downing their first German bomber almost at first try.

The man credited with the development of this weapon is Dr. Alwyn Douglas Crow who had been an infantryman in the First World War and emerged as controller of projectile development of the British Ministry of Supply in the Second. Dr. Crow, upon hearing of certain German experiments with rockets which will be discussed in the next chapter, ordered his technicians in 1934 to go ahead and see what rockets could do in modern war.

The men who were put to work on "Development U.P." (Unrotated Projectile) soon reported that anti-aircraft rockets should be useful, especially against dive bombers and low-flying planes. In that case it is not the accuracy of each single round fired, but the over-all accuracy of a large number of rounds, which counts, and rockets were capable of delivering just that type of fire. "U.P." was ready for final tests in 1938 and then, for reasons of secrecy, was shipped to Jamaica in the West Indies, where the tests took place.

They were very impressive; the dense salvoes of rockets literally created a screen of exploding shells in the air. The weapon was accepted and called *Z-guns*, a term which occurred only in official correspondence and news releases. The British soldiers handling them talked about their "whoopees" and whoopee guns. They were used all through the war in steadily increasing numbers. Many of the *Z* batteries were later operated by the British Home Guards.

If the German *Stukas* considered the English coastal convoys easier prey, they received their second surprise: rockets again. This time it was a British Navy type which did not carry a shell

aloft. These navy rockets rose high into the air and then ejected a length of steel tape which had been wound up tightly inside. The whole was carried by a small parachute and floated slowly down, a deadly obstruction for any plane which tried to dive through the webs of dangling steel tape.

After the *Luftwaffe* had been beaten back, the Germans, after a pause, attacked Russia . . . and then the rocket war began in earnest. The Germans brought up their *Nebelwerfer*, but meanwhile the German Panzers had taken a severe beating from Russian rockets. One of the Russian rocket weapons, which looked like a big box on wheels, discharged thirty rockets at once with one enormous backblast, like a gigantic shotgun discharge. But if the German tank drivers feared this weapon, they were simply terrified of another one that swooped down on them from the sky.

It was what must technically be called a "rocket-accelerated airplane bomb" but newspaper writers often called it an "upside-down rocket," a term sadly lacking scientific precision and void of all military solemnity—but very descriptive.

The idea was this: the power of a bomb to penetrate armor depends on its impact velocity. Roughly speaking, a bomb that hits twice as fast hits four times as hard, one that hits thrice as fast hits nine times as hard. Now the airplane bomb ordinarily obtains its speed from one source only, from the earth's gravity which causes it to fall. Naturally bombs dropped from higher altitudes, with more time to fall, arrive with a higher impact velocity, but there is a limit even to that. If the plane which drops the bomb is high enough, the bomb reaches what is called its "terminal velocity." It cannot go beyond that, because it is the velocity where air resistance counterbalances the action of gravity.

For most bombs the terminal velocity is a little over 900 feet per second and they reach that terminal velocity when dropped from altitudes beyond 20,000 feet.

Since bombs from a dive bomber are usually released at 2000 or 3000 feet, the speed which would result from falling alone is not too high. As these bombs have the additional speed of the diving plane, however, they arrive with a higher velocity than if they were just dropped from that altitude. But the increase does not amount to as much as one would think at first glance. The bomb from a dive bomber arrives with just about half the impact velocity it would have if it had simply been dropped from about 20,000 feet..

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The thought that a rocket charge in the tail of a bomb could be used to push it down against increasing air resistance occurred to me a number of years ago, and in the fall of 1940 Schaefer and I set out to test this idea on a few examples. The result was an article entitled *How about Penetration Bombs?* Which made the rounds through the editorial offices of several technical and semi-technical magazines without evoking much response. It was finally printed in the December 1941 issue of the *U. S. Naval Institute Proceedings*. (See Appendix 2.)

Just three months later we learned that others had had the same idea. Reports from Russia said that a specific airplane type, the *Shturmovik* or *IL-2*, ruined German Panzer formations by using just such rocket-accelerated bombs which hit with 800 feet per second. They were later copied by the Germans and used in attacks on Malta and against British shipping in the Mediterranean.

And at Stalingrad the massed pocket of General von Paulus' men came under the concentrated fire of still another Russian rocket weapon, a weapon which was used for the beating of large target areas on the ground. That weapon came in two forms. One was strangely reminiscent of Congreve's ladder-like launching racks. It looked like a very wide step ladder which was placed on the ground and the rockets were placed on it, side by side. The other variety was more modern in appearance. A series of projector tubes were mounted on a truck and formed highly mobile rocket batteries.

Stalingrad meant the turn of the tide.

The Allies were ready for counterattack and the Americans landed in North Africa. And the once invincible Panzers of the Nazis faced still another rocket weapon, a small portable launching tube which delivered incredible blows for its size. They faced the most famous of all American rocket weapons, the *Launcher*, *Rocket*, *M-1*, of official registry, the *bazooka* of the soldiers that used it.

It is a matter of historical record that the commander of a group of German tanks in Africa surrendered to some American soldiers, thinking that he had been caught in a trap where he was under fire from 155-millimeter howitzers. It had been *bazooka* fire.

When the existence of this weapon was revealed for the first time by Major General L. H. Campbell, Jr., early in 1943 and it was explained that this comparatively small rocket weighing only a few

pounds could destroy a tank, most people jumped to the conclusion that the *bazooka* was so effective because of the high speed of the rocket projectile. Actually the bazooka projectile moves very slowly; it can even be seen when it races toward its target. The secret of its great destructiveness had nothing at all to do with the fact that it was rocket-propelled. The secret was in the demolition charge carried by the projectile. It was a so-called "shaped charge."

The "shaped charge" had been invented, or, if you want, discovered, almost half a century ago by the late Dr. Charles E. Munroe, an American explosives expert. Munroe was setting off charges of explosive against armor plate at that time. And one day he noticed to his great surprise that a charge which did not fit snugly against the armor plate produced a much deeper penetration than other charges of the same size. He followed up on this accidental discovery, and the first experimental Munroe charge (as it later came to be called) consisted of a bundle of sticks of dynamite, tied together in such a way that only the outer circle of dynamite sticks touched the armor plate while the inner sticks of the bundle had been pulled out for a few inches. The result of this explosion was a concentrated blast of fire which penetrated the armor plate to any depth desired.

It was easy to visualize what actually happened in an explosive charge from which a hollow had been scooped out. The explosive energy was concentrated very much in the same manner in which the reflector of an automobile headlight concentrates the light from the bulb. When a shaped charge is set off upside down, pointing skyward, the explosion actually looks like a momentary stab of a searchlight beam.

One would think that military men all over the world would have seized upon the discovery of the shaped charge. But, strange to relate, not a single shaped charge was used all through the First World War at the fighting fronts—but all through that war German and Swedish mining engineers used shaped charges underground in their mining operations. Nobody paid any attention to them.

The reason the bazooka rocket was such an effective carrier for a shaped charge was just that it is comparatively slow. A shaped charge, to be fully effective, had to go off a little distance from the armor plate that it is suppose to penetrate. The long nose of the bazooka projectile provides that distance, and since the movement of the rocket is comparatively slow that distance is not appreciably

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shortened during the tiny interval of time which the fuze needs to work and the charge needs to go off. In a fast-moving artillery shell things obviously cannot be timed so well, which is the reason shaped charges have been used in artillery projectiles only in a more or less experimental manner.

Not all shaped charges are of necessity carried by rockets. A German anti-tank weapon called *Panzerfaust* ("tank fist") which has a shaped charge is fired by means of a greatly undersized cartridge. Nor do all rockets carry shaped charges. In fact the majority of them do not; their warheads are built along the lines of ordinary projectiles. It depends entirely what the rocket is supposed to do. If it is an anti-tank weapon for direct fire, in which the projector tube is aimed in the manner of a rifle, a shaped charge is indicated. If it is a rocket that is used like a howitzer shell (the Russian rocket thrower, the German *Nebelwerfer*, and the American 4.5-inch rocket) there is no need for a shaped charge.

From North Africa the war moved on into Sicily, and there the *Nebelwerfer*, which up to that time had not been a very frequent weapon, was encountered in quantities. And it was no longer just one kind of *Nebelwerfer*, with 15-centimeter rockets fired from six-barreled projectors. There existed a larger type, with a caliber of 21 centimeters (about 8¼ inches), and its projectors came in several forms. One looked like the original *Nebelwerfer* but with only five tubes. Then there was one in which the five projector tubes were placed not in a circle but side by side. That arrangement was also used for the 15-centimeter *Nebelwerfer* on occasion. And there was a super-type of the large *Nebelwerfer*, mounted on tanks or railroad cars, with ten projector tubes in two layers of five each.

If the 15-centimeter *Nebelwerfer* had had a range of from 6000 to 7000 yards, the heavier 21-centimeter variety could reach up to 9000 yards.

But the two varieties of *Nebelwerfer* were no longer the only German rocket weapons on the ground. They had been joined by another, and its name was *Schweres Wurfgerät*.

The name was a revival of the old term for the medieval siege engines, the *ballistae*, which lobbed heavy stones into besieged towns. While it could be rendered simply as "launching device" the name preserves more of the flavor intended if translated literally as "Heavy Throwing Engine."

It was a weapon which utilized a 21-centimeter rocket, presumably the same rocket which propelled the projectile of the heavy *Nebelwerfer*, in a different manner. A bulky container for a mixture of oil and gasoline was attached to the propelling rocket. That container measured 32 centimeters in diameter and held about 11 gallons of liquid. The whole looked like a huge warclub of old and weighed over 200 pounds.

At first the *Wurfgerät* came singly, in individual packing crates which served as launching racks after the outer cover had been removed. The crates were just stripped of their outer wrappings, were propped up on anything that happened to be around, and were ready for use, huge incendiary bombs which traveled under their own power to a distance of about 2000 yards.

Some of these 32-centimeter *Wurfgerät* projectiles were found with a yellow cross painted over their noses. This is the German marking for mustard gas, but when these projectiles were opened by men of the Chemical Warfare detachments the projectiles were found to be oil-filled like the others.

The method of firing these rockets individually from their shipping crates had apparently proved reasonably accurate on the testing grounds, but the Germans soon found that it did not work too well under battlefield conditions. To increase the accuracy somewhat and to provide for a higher volume of fire at the same time, they then put six of these crates together, in two layers of three each, and mounted them on a gun carriage.

At about the same time they produced a smaller *Wurfgerät* by reducing the bulbous warhead to a diameter of 28 centimeters and filling it with high explosive.

Significantly, the use of the heavy ground warfare rocket shifted from the Germans to the Allies, and especially to the Americans after the invasion of Italy (See Appendix 2 for list of American rocket weapons.) The howitzer-like ground bombardment rocket is an offensive weapon and Allied strategy had reached the point where waiting defense was transformed into well-mapped attack. Unlike the gun which, with its pinpoint accuracy, does as well in defense as in attack, rocket fire, with its violent area beating, has less defensive value. It is the weapon which beats the path for the storming tanks and the occupying infantry.

The Americans had two rockets ready for just this purpose, the 4.5-inch which looked like a finned shell and the 7.2-inch which

looked like a small airplane bomb. The small bazooka rocket, developed to ward off tanks, had been 18 inches long with a largest diameter of 2.36 inches, the diameter of the shaped charge. The diameter of the propelling charge had been about half that and the total weight $3\frac{1}{8}$ pounds.

The heavier rockets did not have shaped charges; they were not specialized weapons but projectiles calculated for mass expenditure, a mass expenditure which, for a while, came to 120 million dollars per month. The 4.5-inch rocket was more versatile than the 7.2-inch type. The 4.5-inch, of uniform thickness along its whole length, weighed 38 pounds and had about the same destructive power as a 105-millimeter howitzer shell. Still, it was a one-man weapon. It came singly, in a packing tube which was also the launching tube, with camera-style tripod attached, which was considered expendable. The total weight was 50 pounds, not too much for one man to carry.

Fired from launching tubes slung under the wings of Allied fighter planes, three or four under each wing, 4.5-inch rockets blasted ground targets that would have been artillery targets if they had been in artillery range. They exploded the locomotives of troop and supply trains, they wrecked tanks and motor columns. They sank barges in Dutch canals, they wrecked specific buildings, they were sent flaming into enemy fuel depots and ammunition dumps. Fitted with proximity fuzes they shot down enemy aircraft and strafed troops on the ground.

They—as well as the 7.2-inch type—were massed on the decks of special “rocketboats,” rack after rack of self-propelled projectiles, fired electrically from below deck to fall as a dense hail on Japanese island positions. One such rocket boat could, in the space of a few minutes, throw as much steel and high explosive as the turrets of three battleships. The invasion of southern France was accompanied by a hail of 40,000 rockets.

These bombardment rockets were typical breakthrough weapons, capable of producing a literal rain of explosives for a short time, preventing any effective counter measure while it lasted. When on land the tanks took over with the same weapon. Sixty projector tubes for 4.5-inch rockets, in four tiers, were mounted over the turret of an M-4 General Sherman tank in an organ-pipe-like assembly that became known as *Calliope*. The projector assembly turned with the turret on top of which it was mounted, and

a hinged rod, connecting *Calliope* with the 75-millimeter turret gun, made it possible to elevate the projector tubes by elevating the tank gun.

A special electrical firing arrangement, developed by Western Electric, enabled the gunner to fire the rockets in rapid succession, but never two adjacent tubes simultaneously or in quick succession, so that the exhaust from one rocket would not disturb the trajectory of the other.

A secret device, secret all through the war, was the *Anti-Submarine Projector, Mark 10*, known as the "hedgehog." It was originally a British invention, but adopted and improved by the U. S. Navy. Its full charge was 24 heavy rockets, which could be fired in $2\frac{1}{2}$ seconds. They fell in an elliptical pattern in the area which marked the approximate location of a submarine and sank immediately, heads down. But their charges were not conventional "depth charges," they exploded only on contact, not when reaching a specific depth. The sound of an underwater explosion, therefore, was definite proof that a submarine had been hit.

Meanwhile German rockets had taken to the air too.

They had developed an 80-millimeter rocket which they fired from Focke-Wulf fighter planes. When these rockets were new, they caused considerable losses from an American bomber formation of Flying Fortresses over Schweinfurt, but their value as an air-to-air weapon did not last long. The Focke-Wulfs carried only two of these rockets, one under each wing; after they had been fired the planes had to rely on their ordinary armament. The first success had been due solely to superior tactical employment—similar to the superior tactical employment in North Africa which accounted for most of the reputation of the 88-millimeter gun. Besides it was obvious folly to rely on a relatively slow projectile as a weapon against fast-moving aircraft, especially with a very limited supply of such projectiles.

The Germans made up (or tried to) for this drawback by special tactics which soon wore off. The Americans remedied the same drawback by a proximity fuze which did not make direct hits necessary.

These German rockets were also fitted with a shaped charge for a warhead and used as an imitation *bazooka*, but rarely, since they had the *Panzerfaust* which was adequate for close-range work.

Quite a number of German rocket weapons failed to emerge

from the testing grounds in time, or failed, at least, to be produced in sufficient numbers to be used. The most advanced of these unfinished German weapons was *Schmetterling* ("butterfly") of *Junkers Flugzeug und Motoren Werke*. It was the weapon for which the German Ministry of Propaganda had reserved the designation V-3—to be used when *Schmetterling* would go into action. One of the research chiefs of the firm of Junkers, Professor Wagner, did not hesitate to claim that each *Schmetterling* would account for an Allied bomber.

In appearance it was a small airplane, 13 feet 1¼ inches long, with a wing span of 6 feet 2 inches. The fuselage, 13½ inches in diameter, had a forked nose, one side carrying a long conical war-head, the other a 6½-inch four-bladed impeller which activated the electrical devices.

Two rocket units, mounted on top of and below the fuselage and working either simultaneously or separately, made *Schmetterling* extremely speedy. It could attain a maximum speed of 620 miles per hour with a range of about 20 miles and a ceiling of 50,000 feet. The rocket units were dropped off when expended, in order to reduce air resistance. When ready for launching *Schmetterling* had a total weight of 350 pounds; it was ground-launched and guided by radar by a ground crew.

While by no means perfect, *Schmetterling* would have been an effective anti-aircraft weapon if it had existed in sufficient numbers. But the very airplanes which it was supposed to destroy delayed its development. At the time of the German collapse the first production model had just been made ready.

Schmetterling was a representative of a new class of weapons which go under the name of "guided missiles" and which were under development everywhere during the latter part of the war. In Germany, specifically, all aircraft manufacturers and some armament manufacturers had received instructions to concentrate on the development of anti-aircraft weapons some two years before V.E. Day, and most of them had turned their attention to guided missiles. Most of the guided missiles, in turn, were rocket-propelled.

The *Forschungsinstitut Hermann Göring*. (Research Institute Hermann Göring) had produced a winged torpedo which had the specific purpose of being a research instrument for guiding missile research. This development, called *Feuerlilie 25* (Firelily 25) was

a medium-sized model of a very high-speed airplane, propelled by a powder rocket with a burning time of 6 seconds.

The only one of the German guided missiles to see action was the Hs 293, a development of the aircraft manufacturing firm of Henschel. It was a winged bomb weighing about 1700 pounds and 11 feet 8 inches long. The wings had a spread of 9 feet 6 inches and it carried a rocket in the extreme tail end of the fuselage. The Hs 293 was used late in 1943 and early in 1944 as a weapon against Allied convoys. The bomb was carried out to sea by German long-range bombers, Dornier Do-127, Heinkel He-177, Junkers Ju-290, and Focke-Wulf FW-200. Each bomber could carry only one of these bombs—of course they also carried some ordinary bombs inside. When within sight of an Allied convoy the winged bombs were released and their rockets began to work. The launching airplane could guide the bombs by radio—it is a matter of record that either the guiding mechanism did not respond too well or that the guiding radio men badly lacked training and experience. Just the same the Hs 293 accounted for several Allied merchantmen.

When the Henschel factories fell into Allied hands it was found that another such missile had been developed there in the meantime. It was the Hs 298, a small missile, only 6 feet 7 inches long and with a wing span of 4 feet $2\frac{3}{4}$ inches. It weighed 210 pounds. The nose arrangement of the Hs 298 was copied from that of *Schmetterling*, except that the warhead had been located above the impeller. Hs 298 was supposed to be launched from aircraft against other airplanes, but could also have been used against surface ships or even stationary targets.

All these guided missiles have to be classified as aerial counterparts of the naval torpedo, and it is greatly interesting to a historian of technology to see that almost all of the ideas embodied in the early experimental naval torpedoes returned for a try-out in the winged torpedoes of the air war. Many of the early naval torpedoes had been equipped with electric light bulbs sticking out on long thin rods, so that the torpedoman could follow their course or, in torpedoes so designed, could guide them. (They were all meant for shore batteries.)

There is hardly one among the modern guided missiles (no matter whether German or American) that does not carry an enormously brilliant guide flare, usually attached to one of the stabilizing fins.

Some of the early naval torpedoes had trailing wires, either to supply them with power or to guide them, which fouled with monotonous regularity.

The Germans had an air-to-air rocket with trailing wires. This was the X-4, a cigar-shaped liquid-fuel rocket (burning hydrazine hydrate and alcohol) with an over-all length of 6 feet 8 inches and carrying a 50-kilogram (110-pound) warhead. It had four rather small stabilizer fins at the tail end, arranged in a cruciform shape, and four very short wings near the center of the body, arranged in the same manner. These wings spanned only 19 inches, while the body of the rocket was $8\frac{1}{2}$ inches in diameter. Two (opposing) wings carried guide flares, the other two carefully streamlined 24-inch bobbins, each holding 6 kilometers (about 4 miles) of very fine insulated copper wire.

When released from the bomb bay of the defending plane the X-4 forged ahead with more than twice airplane speed, unreeling the wires through which the pilot would send electrical impulses to the rocket's control mechanism.

These winged rocket torpedoes were joined by several other anti-aircraft rockets which, while anything but conventional in design, were more deserving of the appellation "rockets." One of them was *Wasserfall* (waterfall) which existed in many slightly different experimental types. It was a torpedo-shaped rocket, standing 24 feet tall, with four stabilizing fins at the lower end and four wide stubby wings near the center of its body. The take-off weight was $3\frac{1}{2}$ tons, the propellants were *Visol* (German code name for vinyl ether) and nitric acid as an oxygen carrier.

Counting from the top down, *Wasserfall* housed the following things: A radio fuze, exploded by radio from the ground, formed the nose; it was to be replaced later by a proximity fuze. Then came the warhead, filled with *amatol*. The top compartment of the rocket proper, which had a diameter of 3 feet, was a spherical pressure bottle charged with compressed air which operated the control mechanisms. The valve compartment was placed immediately below that pressure bottle. Then came the *Visol* tank and the nitric acid tank and finally the power bay, housing the rocket motor and auxiliary devices. The stabilizers and vanes were attached to the power bay from the outside, the short wings to the outside of the compartments housing the pressure bottle and the *Visol* tank.

Wasserfall had progressed to test ascents and may even have been used experimentally a few times. Records of some four dozen experimental launchings were found, but these records also stated that the rocket was a "full success" (*voller Erfolg*) only in twelve cases; only one out of four performed as expected. Because of its weight *Wasserfall* was launched from the ground.

The last of the unfinished German anti-aircraft rockets which had progressed to an experimental stage was one of the most fantastic-looking devices human eyes have ever seen. Its name was *Rheintochter*—"Rhinemaiden"—and it was a slender 20-inch rocket, 11 feet and 10½ inches long. It had four large control surfaces in cruciform arrangement near its nose and six enormous sweep-back wings around its tail end. Six rocket exhausts were arranged there too, emerging slantwise between the wing roots. The nose was a proximity fuze called *Kugelblitz* ("ball lighting"), followed by a compartment housing the motors which moved the four large control fins attached to the outside of that compartment. The next section contained the gyroscopes, the one after that the radio. Next came the fuel compartment followed by the rocket exhausts placed between the roots of the six wings. The reason for having six wings was probably that the designers expected that the rocket might slowly spin around its longitudinal axis. Six big wings, and four large control surfaces, were presumably required to reduce such spinning to a minimum. But if the rocket did spin in spite of all these precautions there would also be one pair of wings in position to provide lift.

Rheintochter was supposed to operate by means of two correlated radar plots from ground radar stations, one on *Rheintochter* and the other on the bomber to be destroyed. With all these parts required for propulsion and control there was no good place left for the warhead except the tail end, so the war "head" came last, forming the bottom compartment of the whole rocket.

But it was not the bottom compartment when *Rheintochter* took off from an inclined ramp. Then *Rheintochter* was fitted with a booster rocket, 22 inches in diameter and just 1½ inches short of 5 feet. The booster unit had another set of four large wings, set cruciform. At a height of 2 kilometers the booster unit dropped off. The rocket proper was capable of climbing another 6 kilometers so that its ceiling was in the neighborhood of 20,000 feet. Since this was obviously too little, development on the original *Rheintochter*

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also referred to as R-1, was discontinued and an improved version called R-3 was constructed.

The Allies had many similar guided missiles under development when the war stopped. The only one which saw a fairly extensive use in the Pacific was a target-seeking radar glider bomb called from its appearance *The Bat*. But *The Bat* was not rocket-propelled, and the two American guided missiles that were, apparently did not see action.

They were *Little Joe* and *Gorgon*. *Little Joe* is in appearance a blunt-nosed bomb with four large stabilizing fins at the tail end and four small control surfaces near the nose. Its main propulsion unit is a 1000-pound thrust unit of the type used for rocket-assisted take-off of aircraft. Four additional solid-fuel rockets are attached externally between the stabilizers, one of which carries a guide flare. The high-explosive charge weighs 100 pounds and is fitted with a proximity fuze. *Little Joe* was developed especially as a counter-weapon against the Japanese *Kamikaze* attacks but can serve as an all-purpose guided missile launched either from the ground or from aircraft.

The other, *Gorgon*, is a rocket-propelled small airplane of the so-called canard type, also known as a "tail-first airplane." It is 16 feet long and its main wings, which are in the back, span 11 feet. The power plant is a rocket motor burning aniline and nitric acid. Official designation of *Gorgon* is KA2N-1, meaning pilotless (K), anti-aircraft (A), Naval Aircraft Material Center (N). The "1" stands for "first design," and that first design has a level speed of better than 500 miles per hour.

But on the other side there was V-2!

Chapter 9:

PEENEMÜNDE!

*"Wisdom is better than weapons of war;
But one sinner destroyeth much good."
—Ecclesiastes 8:18.*

THE Bay of Stettin is separated from the Baltic Sea by two large islands, both roughly of a triangular shape. The island to the west is named Usedom, the one to the east Wollin. Since there are two islands, there are, naturally, three channels connecting the bay and the sea. Their names, from west to east, are Peene, Swine, and Dievenow.

Where the Peene joins the sea there existed for many many years a small and poor village of fishermen. About half a century ago, when other fishing villages along the coast changed into seashore resorts enjoying a prosperous summer trade, the small village at the mouth of the Peene tried to follow suit. But while the others prospered this one remained small and unprosperous. The coast-wise steamers, painted a festive white and complete with brass band, which began their trade route at Swinemünde and finally ended up in the fashionable seashore resorts on the island of Rügen—passing within a few hundred meters of the *Greifswalder Oie*—did not even call there, at least not every day.

Their last stop at the island of Usedom was Zinnowitz, and when you left Zinnowitz, going to Rügen, you saw on the receding coastline, at the extreme northwest tip of the island, one more small place. The ship's officers, when asked about it, used to say: "Oh, that. No, we don't call there, it doesn't pay. Name of the place is Peenemünde."

Peenemünde—"Mouth of the Peene."

Hardly anybody knew the name then. But there is hardly anybody now who does not know it. Because Peenemünde stands for the biggest accomplishment in rocket research so far; it stands for V-2.

It was near Peenemünde where the German army founded a

rocket research institute late in 1937. It was not named originally after the seashore resort, but the geographic affinity transferred the name to it so that those in the know did not even speak about the institute any more but just said "Peenemünde."

The construction work at Peenemünde began with a so-called *KdF* Hotel built by the German Labor Front. This organization, which was Hitler's substitute for trade unions, boasted loudly about a department called *Kraft durch Freude* (Strength through Joy), the activities of which consisted in providing theater tickets at greatly reduced prices, ditto vacation trips and so on, theoretically for all its members, actually mainly for those who had friends in the organization. If you were a *Sturmführer* or higher up in the party hierarchy you could get tickets without having a friend in the *KdF* Office.

But no amount of influence, no well-established old friendship, could provide a vacation in the *KdF* Hotel near Peenemünde. It was *KdF* by name only, even though probably administered and run by *KdF*. Actually it was Army and that with a capital A. It existed solely and exclusively for the research workers and engineers of the rocket institute and for their *Gestapo* supervisors.

When the war began, the institute was working full blast and in absolute secrecy. In spite of all that the Allies, especially the British, knew well what was going on. It is said that the British Secret Service had two agents right in the institute itself.

Early in 1942 the British knew that things had progressed to a stage where results could be expected. The RAF went over for photographic reconnaissance and, in order not to tip the Germans off about the fact that they knew what they wanted to reconnoiter, photographed the whole Baltic coast from Kiel to Rostock. To further justify their activities the Bomber Command sent mine-laying bombers over every once in a while. The mines incidentally delayed and partly destroyed German convoys bound for the Russian front.

In time the people at Peenemünde became used to having RAF planes overhead and did not even seek shelter any more. RAF pilots reported that they remained in the open, looking curiously at the British planes.

Lulling the Germans into carelessness in that manner brought results. In 1942 RAF planes returned with a photograph of a part of the Peenemünde Institute, showing something that looked like

a tiny airplane on a launching ramp. It was one of the early models of V-1.

Soon afterward stories began to come from southern Sweden and from the Danish islands in the Baltic that something strange was going on on the German side. Fishermen out at sea had seen strange things flying through the air at high speeds. Occasionally one of them crashed on one of the islands and was found to resemble a small airplane, too small to have room for a pilot. The reports spoke about fragments of equipment that had been scattered around, fragments which looked as if they belonged to a steering device of some kind. Some of them definitely were parts of radio sets. One point was mentioned again and again. There was always one compartment in these devices which was filled solidly with concrete. That compartment, obviously, would house the explosive charge, replaced in the experiments by concrete.

At the time when the Allies permitted these reports to be distributed over the press wires the RAF had already done its work. As was later revealed, an enormously concentrated and incidentally very expensive air attack on the no longer secret research laboratories had been performed during the night of August 17-18, 1943. When announcing this raid several months later Prime Minister Winston Churchill told the House of Commons with typical British understatement that "great damage had been done to the enemy and his affairs."

That damage was all the greater since it so happened that a full "bomber's moon" in the sky coincided with some kind of special meeting below. When the RAF bombers roared in, seemingly en route to Berlin, there were, according to unofficial sources, close to 7000 researchers, army officers, and political leaders assembled at Peenemünde. We now know that 1500 of them perished in the raid. A large number of others were killed by the *Gestapo* which raged through the ruins throughout the remainder of the night and the next day, hunting "traitors and agents." Among those killed, either by British bombs or by *Gestapo* bullets, were the *Kommandant* of the institute, Major General Wolfgang von Chamier-Gliesezenski. Among the dead was General Jeschonnek, the *Luftwaffe's* Chief of Staff. And it is now a generally accepted theory that Ernst Udet, whose death was announced a few days later, actually died at Peenemünde.

The living quarters of the research personnel, those *KdF* establishments, had been almost completely destroyed, the majority of the workshops had burned down, many of the storage buildings had blown up. Strangely enough the main test building escaped, and some of the key men of the scientific personnel were unharmed.

In one respect the raid had come too late. By the time the majority of the buildings at Peenemünde crashed under the weight of British bombs the new weapons which had been developed there were already in production. One may say that these new weapons, later so famous, were not fully developed, in fact that they showed a number of glaring imperfections. In spite of those imperfections they had reached a usable state. A "usable state" was good enough for the hard-pressed Germans. Consequently the two main products of Peenemünde, the flying bomb V-1 and the long-distance rocket V-2 were in mass production throughout Germany. Both were still used during the last phase of the war and while they failed to alter its course they transformed the face of war for all time to come.

It was *after* the destruction of Peenemünde that the German Ministry of Propaganda began to indulge in the unique performance of announcing to the world that Germany had an arsenal of secret weapons which would be put into action "as soon as the Führer gives the word." That performance was unique mostly because the main value of any new weapon lies in surprise use. But the Nazis presumably knew that their V-weapons were not only known to the Allies, but that counter preparations were in full swing. They may have known that the RAF was testing tactics for destroying the launching ramps for V-1 flying bombs while the *Organisation Todt* (the Nazi Engineer Corps) was working day and night in northern France constructing such launching ramps. They may have learned that American army engineers were actually building a few such launching sites in this country for our Air Force to practice on.

All through the winter of 1943-44 building and bombing competed with each other along the so-called Rocket Gun Coast, the French side of the British Channel. Allied bombing could not completely prevent German building, but it did delay the use of the V-weapons again and again. In fact the ponderous launching ramps did not go into action until after D-Day.

The first specimen of one of the new weapons crossed the Channel in the late evening hours of June 12, 1944, crashing into London some 15 minutes later. Contrary to German propaganda and general expectations it was not a rocket, but a pilotless miniature airplane, automatically kept on course by a simple robot pilot and carrying its own propulsion machinery. Since the launching crew could not influence its course to even a slight extent it was not a guided missile, but it was a perfect aerial counterpart of the naval torpedo, being a self-propelled automatically steered explosive-laden miniature airplane, just as the naval torpedo is a self-propelled automatically steered explosive-laden miniature submarine.

(The idea was not new; in fact if the First World War had lasted longer German cities would have been subjected to bombardment by such weapons. In 1918 American engineers experimented with such "flying bombs" on Long Island, not far from New York City. They were airplanes with automatic control devices and powered by a Liberty engine which was supplied with fuel for a 400-mile range. The Armistice came before these experiments were finished.)

This aerial torpedo became known as V-1, the V standing for the German term *Vergeltungswaffe*, meaning revenge weapon. The V designation was an invention of the German Ministry of Propaganda which had, at first, named it *Wunderwaffe* (miracle weapon) but had been crossed up by the Nazi-inspired tendency to abbreviate everything which made *Wuwa* out of *Wunderwaffe* . . . and *Wuwa* sounds about as funny to a German as it does to an American.

V-1 had a fuselage 25.4 feet long, the nose of which was a so-called warhead housing 1000 kilograms (2200 pounds) of high explosive. Behind the warhead there was a fuel tank holding 80-octane gasoline. Then came two wire-wound spherical steel containers holding compressed air for the operation of the vanes, etc. The tail end was occupied by a simplified robot pilot capable of holding the flying bomb on a straight course and at a given altitude. The wings marked the position of the fuel tank; they spanned 17.67 feet. The most interesting innovation was the "propulsive duct," mounted on back of the fuselage and looking somewhat like an old-fashioned cannon barrel.

Disregarding this propulsive duct, the whole looked surprisingly

like Dr. Sänger's sketch of his projected rocket airplane (see Fig. 46) so that many writers credited Dr. Sänger with the invention of V-1, but that resemblance was probably accidental.

The propulsive duct was simply a steel tube, open in the rear and closed in front by spring-mounted shutters which were forced open by sufficient air pressure on the frontal end. When the air forced these shutters open and entered the tube it provided the necessary oxygen for the combustion of a fine fuel spray present. The resulting explosion forced the shutters tight and resulted in one impulse of thrust. When the combustion gases had been exhausted through the rear nozzle the air forced the shutters open again and a second impulse resulted. The duct worked intermittently, and at night this could clearly be seen from the ground. On night photographs the series of explosions looks like a string of luminous beads. Fuel consumption amounted to a gallon per mile, and the tank held about 150 gallons.

Naturally such a propulsive duct cannot work unless it is in motion, and the flying bombs had therefore to be brought up to a speed of at least 150 miles per hour. This could be done (and was done on occasion) by a take-off carriage with a number of powerful powder rockets attached to it. The carriage dropped off after it had done its duty. But most of the flying bombs were launched by a huge piston moving in a tube inside the launching ramp and driven by compressed air.

Once the propulsive duct worked, it quickly accelerated the flying bomb to a speed of around 360 miles per hour, just slightly above that of the Spitfire fighters of that time. The British knew that they had to expect this. Before the bombs were even used British Intelligence had a report on hand describing a demonstration for Hitler, who saw that a captured British *Spitfire* failed to keep pace with a flying bomb. The real Spitfire pilots quickly learned that they could make up for the small difference by diving toward a flying bomb from a greater altitude.

After the bomb had been in the air for a certain number of minutes a clockwork mechanism locked the elevators so that it dived into the ground. When the bomb tilted, any gasoline remaining in the tank flowed away from the propulsion unit, cutting off the engine. In several cases the engine stopped before the dive, which gave rise to the belief that there were two kinds

of bombs, one which stopped and fell steeply and another which stopped and glided. Actually it was the same bomb.¹

Naturally such a weapon was not accurate; even those bombs which were not interfered with by the British- and American-manned defenses between the coast and London showed a dispersion of some 20 per cent of the total range. The average range was 150 miles, longest observed range was 175 miles, but a great number fell short of the normal range of 150 miles by 15 miles and more. With such a dispersion the flying bombs could not be counted upon to hit a target smaller than a city the size of London. Most of the launching ramps later captured by the Allies were pointed toward London, except for one group, unfinished when captured, which pointed in the direction of Bristol.

Parts of these launching ramps were shipped to England for study as were large numbers of captured V-1's. Before that salvaged pieces of German V-1's which had failed to explode had been rushed to America to be duplicated in a hurry. They were manufactured to serve as targets for American fighter pilots to practice on and it *may* have been contemplated to use them as actual weapons against the Japanese mainland. Actually, however, no copy of a V-1 was ever used by the Allies.

Aside from being inaccurate, the flying bomb had the weakness of being interceptible. It could be shot down from the ground by anti-aircraft artillery and anti-aircraft rockets; it was intercepted by fighters which had a target that could neither swerve from its course nor change its speed or altitude and which could not even shoot back. Finally it was intercepted by balloon barrages. It was also dangerous to use—French civilians later told Allied soldiers that the Germans offered as much as 1000 francs a day to Frenchmen as an inducement to help them launch the bombs, since they had lost many crews, partly because of Allied bombardment, partly because so many V-1 bombs crashed at once when leaving the launching ramps.

In spite of all these weaknesses the V-1 bombs did a great deal of damage to London. The official British figures state that during the interval from June 12, 1944, to August 30, 1944, the Germans launched 8070 flying bombs against London. Over 2000 of them, one out of every four, fell into the Channel, crashed immediately, or

¹ Hilary St. George Saunders, official history of the "robot blitz," *Life*, Nov. 20, 1944.

strayed from their course. Airplane interception destroyed 24 per cent of the bombs in flight, A.A. artillery and A.A. rockets accounted for 17 per cent, balloon barrages for 5 per cent. Only 25 per cent, or 2000 bombs, reached London.

They destroyed 24,491 houses, rendered 52,293 more uninhabitable, and damaged over 950,000. They killed 5864 persons, injured 17,197 badly and 23,174 slightly. These figures are hardly higher than what could be expected after a 2000-ton air raid, but the bombardment was much harder to bear because it went on over ten weeks, while an air raid of such weight would hardly last more than one hour.

The first V-1 bomb had crossed the English coast in the late evening hours of June 12, 1944; after August 30 the "robot blitz" dwindled to insignificant proportions, all launching ramps being in Allied hands and the German front lines being out of flying bomb range. Sporadic V-1 attacks continued for many weeks, however, being made by using bombers to carry the flying bombs within 100 miles of the English coast.

As early as July 1944 Swedish sources credited Professor Hermann Oberth with the invention of the flying bomb. A short time later the Germans themselves named one (otherwise totally unknown) Heinz Buse as "inventor" of the flying bomb, while the Free French arrested the well-known French physicist and inventor Georges Claude, a notorious collaborator, for having given the flying bomb to the Nazis. While it seems very likely that Claude contributed some of the features of the design, it is more than doubtful that the invention of this complex mechanism can be ascribed to any one man.

In his speech of July 6, 1944, Prime Minister Winston Churchill had referred to Peenemünde as "the main experiment station both of the flying bomb and the long-range rocket." He had also said about V-1 that "at first our information led us to believe that a rocket weapon would be used." This speech made it clear that the Germans, at least, were experimenting with a long-range rocket.

Churchill, of course, knew that such a rocket existed.

Because of the stories put out by the German Ministry of Propaganda, civilian observers, especially on this side of the Atlantic Ocean, were not so certain. The statements about the rocket itself were obviously lies, while the claims made for its efficacy

were utterly ridiculous. It was said, for example, that the giant rockets, having a range of about 150 miles, caused an "area of destruction" of 20 square miles. Another claim was that the rockets, being "charged with liquid air," would fill the English Channel with artificial icebergs in order to crush an Allied attempt to invade the European continent. A third claim had it that the rocket, weighing 15 tons, was carried aloft by an airplane before being released—at a time when anybody in the field of aviation knew perfectly well that there was no airplane of such carrying capacity, whether German or otherwise.

All these incongruities inspired doubt in the actual existence of such a weapon, and when V-1 came and turned out to be a jet-propelled winged bomb the case seemed to be closed.

The first V-2 crashed down on London in the evening of September 8, 1944.

On November 10, 1944, Churchill officially revealed the existence of this weapon. Reporting to the House of Commons he said: "For the last few weeks the enemy has been using his new weapon, the long-range rocket, and a number have landed at widely scattered points in this country."

But now we have to go back not only to the beginning of the Peenemünde institute but to the very beginning of V-2. The only difficulty is that this point is hard to determine. It is almost impossible to say just where and when the conception of V-2 began.

Did it begin with those rumors about Dr. Goddard's 300-mile rocket torpedo which were spread through the daily press and the magazines of Russia and Germany in the Twenties? Did it begin with Prof. Oberth's idea of long-distance mail rockets which he himself admitted on rare occasions would probably carry dynamite instead of business letters? Did it begin with von Pirquet's classification of rocket research into "registering rocket," "long-distance rocket," and "space rocket"?

It is hard to say, but about 1930 the conception of the long-distance bombardment rocket was ready and finished. The only questions in interested circles were whether such rockets could be built at all and, if so, how they would be built. But while these questions were being asked, the weapon did exist in theory.

It was at that time that a retired German general, Artur von Baumgarten-Crusius, wrote two books which caused violent indignation in the ranks of the German Greater General Staff. If the

author of these books had been just anybody, the Greater General Staff probably would have had him arrested and put away behind the yard-thick walls of an old military fortress like their beloved Küstrin. Or threatened the publisher into withdrawing the books from the market.

But since the writer was a retired General the German army could not just have him murdered and they did not dare to offer more than mild threats to the publisher. The result was that at least one of these two books could be bought in any bookstore as long as the supply of the first edition lasted. (The German army did succeed in preventing reprints.)

It was a cheap novel, "cheap" in every respect. The title was *Vengeance 1938* and it told how valiant Germans, working in great secrecy, had perfected long-distance bombardment rockets. It then went on to relate how these bombardment rockets were offered to the Greater General Staff for the liberation of Germany and how in the end Paris was destroyed by a hail of "German meteors." The political ideas of the writer, who did not have his name mentioned on the title page, were as simple-minded as his military and technological conceptions. After Paris was destroyed, he wrote, and after the "evil influence of France" was eliminated, world peace came about automatically. The General insisted that all the wars of all history had always been caused by France, consequently without France there could be no war any more.

This rather idiotic piece of fiction was followed by another much shorter and seriously meant book to which the author signed his name and which he titled *Die Rakete als Weltfriedenstaube*. In translation this title means *The Rocket as Dove of World Peace* and that is just what he insisted to be the case. Essentially it was a carbon copy of the other book, but somewhat more restricted in tone and without the lurid prophecies. But the author said that war would be first changed and then eliminated by the existence of long-distance bombardment rockets. He went beyond mere theorizing by stating that an otherwise completely unknown (and possibly fictitious) German inventor by the name of Belz had perfected such long-distance rockets. He even printed a photograph of one, which, as any child could see, was constructed of wood and painted sailcloth and modeled along the lines of the spaceship in Fritz Lang's film *Frau im Mond*.

By that time the German army was actually contemplating the

establishment of a laboratory for rocket research. It was already actively experimenting with large-size powder rockets when Nebel tried to interest Captain Becker. And it was this special branch of the German army's research laboratories in which Count von Braun received his commission. After his arrest by American troops in the summer of 1945, Count von Braun claimed that it was he who called the attention of the military authorities to liquid fuels as a rocket propellant and that they switched experimentation to liquid fuels immediately afterwards.

While it is quite likely that that switch took place some time after von Braun became a member of the early experimental station (before Peenemünde) and while it is also likely that the switch took place because of his presence, the statement ascribed to him contained a certain amount of self-glorification.

There can be no doubt that the German army engineers had read Prof. Oberth's book before they even knew of the existence of Wernher von Braun, who was about 12 years old when the first edition of Oberth's book appeared. And it is a matter of record that they continued for some time with powder rockets even after von Braun had become a member of their group. One night in 1932, von Braun came to see his old friends of the VfR and complained bitterly about what he called the stupidity of his superiors. He said that in spite of all theoretical arguments they insisted on powder as a fuel because of the non-storability of liquid-fuel rockets. At the same time he said that they had ("they" meaning the army) achieved remarkable results. He spoke of 30,000 yards, but he did not state whether this meant horizontal range or vertical ascent. In the end he added, presumably because he suddenly realized that he had talked too much, that experimentation had been discontinued. Even the latter may have been true as far as powder rockets of such size were concerned.

In 1932 and 1933 the German army did perform a number of experiments on the island of Borkum in the North Sea. In spite of great secrecy a little about these experiments became known and the rumors of the Borkum experiments, the activities of the VfR in general and of the so-called Magdeburg Project in particular, coupled with the conditions created by Hitler's rise to power, which had taken place in the meantime, resulted in a magnificent hoax.

I am speaking of the so-called Fischer Hoax which claimed that on October 29, 1933, a man by the name of Fischer risked his life

in a 6-mile rocket ascent, the rocket being the work of his brother. The account seems to have originated in the London weekly *Sunday Referee*; at least a copy of that weekly shows the earliest date of all the numerous versions of the story. It also had the most complete account which read, somewhat condensed, as follows:

A sensational secret demonstration of the practicability of the rocket principle applied to flight was made here last Sunday, when Herr Otto Fischer was shot 6 miles into the air within a 24-foot steel rocket and returned to earth safe and sound, though shaken. The pilot who risked his life in this experiment is the brother of the designer and constructor of the rocket, Herr Bruno Fischer. Owing to the disastrous results of a similar experiment made on Rügen in the spring of last year, when the original inventor was killed, the demonstration was made under the cover of absolute secrecy, under the auspices of the Reichswehr, the German War Ministry. The inhabitants of the island knew nothing of the proposed experiment, and no members of the press were called to witness it. For some months the two brothers had been working day and night in Barmbeck, a small village near Hamburg, to complete the rocket, Bruno Fischer having been an assistant in the building of the first projectile. When the projectile was completed it was transported to Rügen with great secrecy. On Sunday morning, at six o'clock, Otto Fischer shook hands with his brother and the small group of Reichswehr officials present to witness the experiment, and crawled into the rocket through the small steel door.

Bruno Fischer and the three officials then retired to a small hollow in the ground about 200 yards away and Fischer closed the switch that sent the rocket on its journey. There was a blinding flash and a deafening explosion and the slim torpedo-shaped body was gone from the steel framework in which it had rested.

A few minutes later it came into sight again, floating nose upward from a large parachute that had automatically been released when it had begun to descend. As it drifted nearer, the steel fins on the outside of the body could be seen moving as its pilot manipulated the rocket so that it would land on the island. A few seconds later it came to rest on the sands a few yards away and Fischer crawled through the door of the rocket, white and shaken, but smiling triumphantly. The journey through space had lasted ten minutes and twenty-six seconds.

"It was a tremendous sensation," he said to the men who had rushed forward to congratulate him. "When the rocket left the

ground I was conscious of a deafening roar and an unbearable weight seemed to be crushing me against the floor of the rocket. Then I lost consciousness for a moment, due to the tremendous acceleration which drained the blood from my head. When I came to my senses and looked at the altimeter before my face, it flickered at 32,000 feet—a fraction over 6 miles—and then began to drop rapidly. I had completed my climb and was descending. Peering through the little glass window in the side of the compartment I could just see the tip of the parachute billowing above me. The next thing that occupied my attention was the tremendous heat of the asbestos floor on which I was standing. The reason was that the rocket had merely been propelled about 200 yards by the initial explosion, and had been driven the remainder of the distance by the rockets in its tail. . . .”

Further experiments will be conducted by the German War Ministry.

The flood of mail I received proved that this alleged report looked convincing enough to the average reader. It cleverly combined features which could be counted upon to revive some vague memories about rocket experiments in Germany in the reader's mind. It also confirmed more or less vague suspicions about German rearmament. Small wonder that it was uncritically believed at once.

But to anybody familiar with German rocket research it contained a large number of glaring errors. In the first place, the choice of steel for a building material was startling, to say the least. Since a rocket designed to ascend 6 miles does not heat up very much, since it neither moves very fast nor takes very long, there is no reason to build it of such heavy materials. The “asbestos floor” was another error; a German engineer would be likely to use another kind of insulating material.

Then there were a few typical layman's mistakes, proving definitely that the writer of that article not only had not seen the secret Fischer rocket but had never seen any kind of a rocket except fireworks powder rockets. The “initial explosion which propelled the rocket for 200 yards” is an example: there is no such thing as an initial explosion. And large rockets, naturally, never disappear in a flash. They always take off slowly and can be seen clearly. They may “disappear” later, when they are too high to be easily seen. The masterpiece was, of course, the description of the moving steel vanes supposed to steer the rocket to a certain spot. The vanes could move as much as one wanted, but they would not noticeably

influence the angle of descent of a load carried by a parachute. The proper way of steering such a load—whether it be a rocket or a man or anything else—would be to tilt the parachute by pulling the shrouds on one side.

The editor of the *Sunday Referee*, when informed about these facts, explained that his policy of editorial secrecy prevented him from disclosing his source of information and he passed lightly over the technological points, saying that his reporter, not being a trained engineer, might have made a few minor mistakes. The point was that these mistakes were not minor; they were of the order of the statement that the big B-29 bomber took off by flapping its huge wings.

Since a glamorous lie is often more attractive than a simple truth, most people could not be convinced that the story was a hoax. It was unlikely that such an experiment could have been made without my knowing about it, but just to make sure I checked up on rocket experimenters by the name of Fischer. Although that happens to be a fairly common name in Germany, there was a conspicuous lack of Fischers in the files of the VfR. There was no member of that name, and while a search of the correspondence files of non-members did bring two or three Fischers to light they did not live in or near Hamburg.

It was comparatively easy to piece the "sources" together. The performance itself was, naturally, an elaboration on the announced performance of the Magdeburg "Pilot Rocket" with the minor change that passenger and rocket descended together in one parachute instead of separately with two parachutes. The "slim torpedo-shaped body" was, no doubt, a description of the Oberth Rocket. The steel launching rack also pointed to that. Whether the hoaxer had any knowledge of the Borkum experiments or whether the "military secrecy" was just a device to prevent exposure remained uncertain.

But this unknown hoaxer was bested by another writer—or was he the same?—who signed himself as W. J. Makin and published an article called "Space Explorers" in the May 1935 issue of *Nash's Pall Mall Magazine* (London). In that article "Mr. Makin" explained that he had heard that some people doubted the secret Rügen ascent and that he had set out to investigate it:

I decided to begin my investigations by flying to the first most elaborately equipped rocket aerodrome, the *Raketenflugplatz*.

A young engineer led me to the records chamber, where not only the work of the *Raketenflugplatz* is carefully recorded, but scientific results from other rocket aerodromes in other parts of the world are collected. (What others? W. L.)

But even as I was combing these records, a heavily built man with a charming smile and a curiously soft voice was introduced to me.

"Herr Otto Fischer."

Even as I shook hands with him I realized that I was meeting the one man who had travelled through space inside a rocket and lived to tell the tale—the first passenger to enclose himself in a steel rocket of some 24 feet, which was shot 6 miles into the air. The rocket was designed and constructed by his brother, Herr Bruno Fischer. In great secrecy it was transported to the island of Rügen. . . .

Later on in the same article I am mentioned too, although "Mr. Makin" does not make it quite clear whether he met me on that occasion, i.e. together with Otto Fischer, or on some other. As a matter of fact he never did; "Mr. Makin's" visit to the *Raketenflugplatz* some time between November 1933 and March or April 1935 (when I was already in New York) is just one more embellishment of the same hoax. It is a poor embellishment, because at the time of that alleged visit neither the *VfR* nor the *Raketenflugplatz* was active.

I have told this hoax in such detail because it is an annoying piece of falsification which still keeps getting into the way of factual reporting and which has been revived again because of V-2. But I must say that my efforts in exposing the Fischer Hoax are beginning to bear some fruit, even though of a strange kind on occasion. In 1945 an Australian newspaper wrote coldbloodedly that "Mr. Willy Ley, the former vice-president of the German Rocket Society, has meanwhile admitted that the story of Otto Fischer is a hoax"—I must admit that I like the "admitted."

I do admit that the unknown hoaxer, in his own peculiar manner, was as much a prophet as General von Baumgarten-Crusius. Crusius had prophesied V-2; that reporter had prophesied Peenemünde, even placing it in the proper locality geographically, just two dozen miles away from its actual site.

The roster of the men comprising the V-2 section at Peenemünde, I am sorry to say, reads very much like a roster of a partial meeting of the Board of Directors of the old *VfR*. Count von Braun

was the man actually in charge of the construction of V-2. Klaus Riedel was one of the chief engineers. Professor Oberth seems to have lorded it over the theoretical department for several years. Johannes Winkler was also engaged in rocket work, but elsewhere.

Of course they did not all go to Peenemünde at the same time. Wernher von Braun and Riedel were first, while Hermann Oberth followed very soon afterward, in 1938, after seven years of inactivity as far as rockets were concerned. By the time Count von Braun entered Colonel (later General) Dornberger's rocket research group of the German army in 1932, Oberth was "home in Mediash," occupied with gardening and childhood diseases (as a father, not as a physician) and had as his main worry the proper methodology for maintaining strict discipline in the classroom. He did not see anybody, but after several years of sulking he admitted a reporter from the Swiss *Neue Zürcher Zeitung*. That was in 1936. The reporter emerged with nothing more sensational than the statement that Oberth continued to investigate the mathematics of rocket performance.

But if the Swedish correspondent of *Time* magazine was informed correctly, Oberth left Mediash just about a year after the interview with the Swiss newspaperman and went to Berlin where he sought and obtained an interview with Colonel Kesselring, the same who was later commander-in-chief of the German forces in northern Italy. During that interview Oberth is said to have convinced Kesselring about the feasibility of long-range rocket bombardment.

There can be no doubt that such an interview took place, but, in all probability, Oberth had been called by Kesselring. It may have been upon recommendation by Count von Braun via Colonel Dornberger. Or it may have been an attempt to check up on von Braun's statements and promises. Like everybody else von Braun presumably quoted Oberth all the time, and his superiors may have felt that they might just as well have Oberth in person around. At any event Oberth was appointed Professor of Astronomy at the University of Berlin early in 1938.

After that von Braun went in for experimentation on a large scale, against the wishes of the Nazis and even of Hitler himself, who did not wish to expend much manpower, time, and materials on the rocket project. But von Braun had the unconditional back-

ing of the Chief of Staff, von Brauchitsch, who probably regarded the long-distance bombardment rocket program as a part of the German atomic bomb program.

The rocket which was designed and tested first at Peenemünde had the code number A-3—Aggregate No. 3. There had been A-1's and A-2's, of course, at Kummersdorf and at Borkum. The A-1, designed in 1933, soon after von Braun and Dornberger had joined hands, weighed about 330 pounds (150 kilograms) and was comparatively small, a foot in diameter and 4 feet 7 inches long. One year later, in 1934, it was redesigned as A-2, only slightly larger in size, but differing in many essentials. It had a 300-kilogram (660-pounds) rocket motor, and the fuel supply lasted for 16 seconds. When fired, at Borkum, it reached an altitude of 6500 feet.

A-3 was a long step forward as far as size went, 25 feet long and 2½ feet in diameter. It weighed, ready for take-off, 1650 pounds, and the rocket motor developed a thrust of 3300 pounds for 45 seconds. It was controlled by vanes operating in the exhaust jet, and, when kept on a vertical course, reached an altitude of 40,000 feet (in 1938). When fired at an angle a range of about 11 miles was attained.

That was still far below artillery performance, but justified trying for a still larger rocket the design of which had slowly grown through the year 1939. In 1940 it was actually built; the name was A-4 or, more precisely, *Fernrakete A-4*. Peenemünde called it by that name and so did official correspondence. But the Propaganda Ministry changed that designation into *Vergeltungswaffe Zwei*, V-2.

The experimenters did not have much pleasure with A-4, or V-2, at first. The first was fired on July 6, 1942 and rose precisely 3 feet off the ground. Then it exploded with enormous violence, destroying the testing station. The second A-4 rocket exploded too, but at a height of 16,000 feet. No. 3 behaved like No. 2. But number 4 was a success; in October 1942 it covered a distance of 170 miles. Number 5, fired a short time later, also functioned quite well, covering almost full range. However, it could not be found afterwards.

There followed a series of thirteen disappointments. The reasons varied: some failed to take off at all, a few exploded, some took off and broke in two before the eyes of the experimenters. If No. 19 had not performed as predicted the development might have been

stopped. But No. 19 did and so did most of the others to follow. In the series from No. 20 to No. 120 only twenty rockets misperformed, mostly by breaking up in the air.

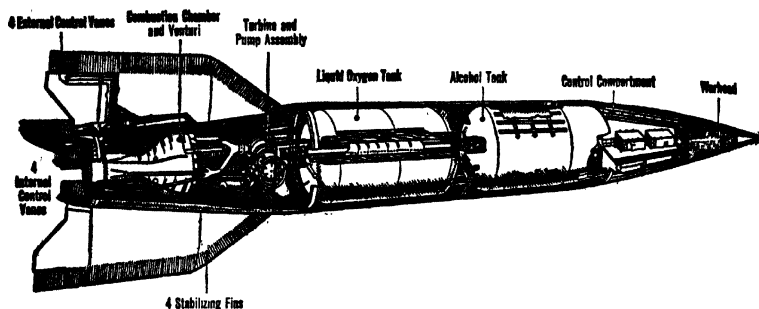
During 1943 Count von Braun went to see Hitler at his headquarters at the eastern front. With him he had rolls of film, documenting the research work done. Apparently both von Braun (who happens to look like the picture of the "perfect Aryan Nordic" invented by the Nazis) and his films impressed Hitler sufficiently to make him change his mind. He ordered mass production of *Fernrakete A-4* which then changed its name to V-2.

It is said that this order was almost rescinded once more by Himmler when a demonstration of V-2 was staged for the edification of high army officers and leading party members with Himmler presiding. The 46-foot V-2 staggered slowly into the air for hardly ten times its own length, then suddenly tipped over and crashed. But since the one-ton warhead had been replaced by a one-ton block of concrete, not much damage was done.

Not all these tests took place at Peenemünde. A large number were performed in Poland where the little town of Blizna was evacuated by the SS in order to make room for the rocket experiments. That had been done in March 1943, a few months before the big raid on Peenemünde. During the six weeks from May 15 to the end of June 1944 over a hundred V-2's were fired from Blizna, fully armed with warheads. The target was the town of Sarnaki, 150 miles due north of Blizna, with about 1000 inhabitants. The SS forced the Poles living in Sarnaki to stay in their town and to lead as much as possible a normal life. The purpose of these test firings was to see what damage a V-2 would cause to an inhabited town and how many casualties would be caused by a direct hit.

The result must have been disappointing. The hundred rockets did destroy a number of houses, but only one man was killed and one woman seriously injured. The town was never hit directly; the closest a V-2 came to making a direct hit was 300 yards from the point aimed at. The town was too small for long-distance rockets.

While one section of the V-2 group dedicated itself to target practice in Poland the other continued research and improvement work in Peenemünde. One rocket, fired in June 1944, exploded high in the air over Swedish territory, showering the countryside with two tons of metal fragments. They were eagerly collected and turned over to the British who succeeded in reconstructing



32. Fernrakete A-4, popularly known as V-2.

This picture (which has been partly redrawn for the sake of clearer reproduction) was released by the British Information Service in November 1944, just two months after the first V-2 fell on London. It was based mostly on the reconstruction of the fragments of a V-2 which had exploded high over Sweden. The drawing does not show the blanket of glasswool covering both tanks. The four internal control vanes are drawn wrong; they were not just rectangles. They were mounted on supports which were circular and touched the exhaust with their flat side at maximum insertion of the vane.

all the important features of V-2 from these fragments. They learned then that V-2 was 46 feet long with a largest diameter of 5 feet and a little over 5 inches. They also could make a very good guess at the probable performance.

These rockets were already mass production pieces, hence they differed little from V-2's used against London and Antwerp.

V-2 took off without a launching tower of any kind, requiring nothing but a piece of reasonably solid ground some 40 feet in diameter. The German launching crews preferred locations surrounded by forest, not so much to escape detection as to provide a windbreak for the rocket which was rather unstable during the first few seconds of ascent. When fired at maximum range the take-off weight of the rocket was about 12½ tons, while the rocket motor developed a thrust of 60,000 pounds at sea level. The acceleration at take-off, therefore, was only about 1.2g effective.

At the end of the first second of actual ascent the rocket had a velocity of 38 feet per second, at the end of the second second it had a velocity of 76 feet per second, at the end of the third second it had a velocity of about 115 feet per second. It can be seen that it rose rather slowly at first, but a steady increase of 38 feet per second for every second elapsed does become noticeable very soon. And since the rocket lost weight at the rate of 275 pounds

per second, not only its velocity but also its acceleration increased very quickly.

For the first 8 seconds of ascent the climb was perfectly vertical, then the control vanes slowly tilted the rocket so that the nose began to point in the direction of the target. Another 40 seconds later the rocket moved at an angle of 45 degrees, throwing itself into the ballistic trajectory which would end, 5 minutes after take-off, with a crash in the target area, some 200 miles from the take-off point. When fired at maximum range the rocket motor had to burn for 71 seconds. During the last few seconds of burning the rocket was about 22 miles high, moving with a velocity of 1 mile per second or 3600 miles per hour. It was then some 22-23 miles above sea level, the motor produced a thrust of 69,000 pounds (the exhaust no longer had to fight much air pressure when emerging from the exhaust nozzle), and the acceleration was just a bit short of 8g.

When the rocket had the proper direction and velocity at the proper altitude the fuel supply was shut off; at first this was done by radio by the ground crew but later the radio shut-off switch was replaced by an instrument which the Germans called *Integrationsgerät*—the English equivalent is “integrating accelerometer.” It was an instrument which measured the velocity of the rocket and which was pre-set so that it would act when the velocity had reached a pre-determined value. After the fuel supply was shut off there followed another 100 seconds of “free ascent” during which the rocket climbed to an altitude of 58 or 59 miles above sea level, steadily losing velocity. Much of this velocity was regained during the descent, until the rocket entered or rather re-entered denser layers of the atmosphere. The actual impact velocity is estimated to have been about 1100 miles per hour.

Since this is higher than the velocity of sound an approaching V-2 could not be heard, but it could be seen, especially since the rocket was heated up by being slowed down in the dense layers of the atmosphere until it often glowed dull red. A few exploded high in the air before reaching the ground. These rockets presumably had a considerable amount of residual fuel left and developed leaks in the fuel tanks so that the mixture of fuel and oxygen ignited when the rocket heated up.

This description of performance is required to understand some features of the construction of V-2.

The body of the rocket was built along the lines of an airplane fuselage, consisting of a number of ring-shaped steel ribs and longitudinal stringers, covered with thin steel sheet. There were four main sections: (1) the warhead, (2) the instrument compartment, (3) the fuel tanks, and (4) the "power bay" or propulsion unit.

The warhead was conical and made of soft steel 6 millimeters (just under $\frac{1}{4}$ inch) thick. It weighed approximately one ton. The filling consisted of *amatol*, a mixture of TNT and ammonium nitrate which is remarkably insensitive to heat. The experimenters knew that the rocket would be heated appreciably during the descent as well as during the powered ascent—it would have been ridiculous if the warhead had exploded accidentally for that reason while the rocket was still on its way up. Actually, as was found by experiment, the rocket did not heat up beyond 650 degrees Centigrade at any point, except in the motor, of course. The warhead was armed with three fuzes, two of which were situated in front of the charge while the third was placed in the rear.

The instrument compartment is the one in which the largest number of design changes took place even after V-2 was actually in use. It contained essentially a few sets of gyroscopes driven by compressed nitrogen and acting upon two sets of vanes, one external set which was built into the stabilizing fins and one internal set of graphite vanes in the rocket exhaust. These two sets of four control vanes each accomplished the task of keeping the rocket vertical during the initial ascent and of turning its nose toward the target later.

There was a radio set by which the Germans could follow the path of the rocket and a relay by which the fuel flow to the rocket motor could be cut off from the ground. Later this relay was replaced by the much more efficient *Integrationsgerät* which represents one of the more important innovations that went into A-4.

The tanks for the propellants followed next, with the fuel tank placed on top of the oxygen tank and the fuel line to the power bay running through the center of the oxygen tank. The fuel consisted of ethyl alcohol mixed with water in a ratio of 3 to 1 by volume which, to use the language of the liquor dealer, made the fuel 150 proof. Both tanks were insulated with a heavy blanket of coarse glass wool. Strictly speaking this insulation was required for the oxygen tank only; apparently this was one of the compromises with

mass production requirements. It may be remarked in passing that A-4 shows such compromises in quite a few places and that a number of those captured were definitely "sloppy jobs."

In spite of the glass wool insulation it was impossible to delay the firing of such a rocket for a considerable length of time after the fueling was finished. According to captured reports, 2 kilograms (4.4 pounds) of oxygen were lost through evaporation every minute. Both tanks were slightly pressurized, presumably to prevent their collapse when partly empty.

The power bay represented the largest number of innovations, each one even more important than the *Integrationsgerät*. A small turbine, operating on steam, drove two fuel pumps which fed the alcohol and the liquid oxygen into the rocket motor with a delivery pressure of about 350 pounds per square inch. These fuel pumps, as will be explained in detail in the following chapter, were the invention that made A-4 possible.

The rocket motor was essentially an enlarged copy of the liquid-cooled alcohol motors of the *Raketenflugplatz*. They were generally of the same shape with flattened top. The material was $\frac{1}{4}$ -inch steel, formed in sections and welded together. The top of the motor held 18 sets of injection nozzles, each set recessed into a roughly hemispherical depression called a burner cup. The burner cups were arranged in two circles, the inner circle consisting of six, the outer circle of twelve. The liquid oxygen, coming from the pump, went through a distributor system and then entered the cups directly. The alcohol was pumped into the cooling jacket and then entered the burner cups.

It seems that ground tests had shown the experimenters at Peenemünde that cooling through the walls and by way of admixture of water to the fuel, was insufficient to guarantee a motor endurance of sufficient length. To make the cooling complete they provided four "annuli" around the exhaust nozzle which had a large number of small orifices through which alcohol was "spilled" into the exhaust nozzle. That way a thin "sheath" of unburned alcohol was formed on the inside of the exhaust nozzle, protecting the metal. Because of this additional use of alcohol the A-4 rocket carried more fuel than was called for by the combustion equations.

Naturally this extra alcohol had no oxygen to burn with inside the rocket motor, which accounts for the exceptionally long exhaust flame of the A-4 rocket.

This solid column of exhaust gases, emerging with a velocity of 7000 feet per second, also turned out to be the most efficient and most reliable way of controlling the rocket. There were, as has been mentioned earlier, two sets of control vanes, four conventional vanes attached to the stabilizing fins and four internal vanes which were shaped somewhat like the conning tower of a submarine and reached into the exhaust blast itself. They could operate with full efficiency as long as the rocket motor was working. The range of activity of the outer control vanes, operating in the air stream, was sorely restricted. As long as the rocket moved at a comparatively slow speed they could not be very effective. And when the rocket had attained a high velocity the outer vanes found little to work on because the rocket had also reached highly attenuated layers of the atmosphere. It can be said without hesitation that the outer vanes were superfluous and constituted an unnecessary amount of dead weight. What the outer vanes could accomplish the stabilizers could accomplish by themselves and all the effective control fell to the inner vanes.

The filling and firing procedure of the rocket was devised with special attention to the heart of the machinery, the turbine which drove the all-important fuel pumps. It was a steam turbine, and the steam was produced in a manner which smacks of a well-known classroom experiment (and hence of Oberth) by bringing together highly concentrated hydrogen peroxide (code name *T-Stoff*) and sodium permanganate. These auxiliary fuels were kept in small tanks inside the power bay.

When an A-4 rocket was to be fired the *Integrationsgerät* was set first. Then the alcohol-water mixture was filled into its tank. The auxiliary fuels for the turbine came next, oxygen last. Ignition of the rocket motor was accomplished—just as in the first days of the *Raketenflugplatz*—by a slow-burning blackpowder cartridge. After that cartridge had been electrically ignited the main fuel valves were opened, permitting both the oxygen and the alcohol to flow into the rocket motor. When the observer was satisfied that the motor was burning properly—though far too weakly to lift the heavy rocket—he started the turbine electrically so that the propellants were fed into the motor forcibly. The turbine needed about 3 seconds to build up to full speed, so that a time interval of from 7 to 10 seconds elapsed between the firing of the blackpowder torch and actual take-off of the rocket.

A total of 4300 V-2's were fired during the interval between September 8, 1944, and the collapse of the western front. The targets were mostly London and Antwerp. All of the first thousand V-2's, fired between September 8 and December 23, 1944, were sent to the London area. A total of 2000 rockets crossed the English coast and 1230 of them crashed into the London area.

During the very extensive discussion of V-2 which began immediately after its existence had been officially announced, experts quickly agreed that the *Fernrakete A-4* constituted a major engineering achievement. Nobody denied the value of V-2 as far as technological aspects went. The German effort proved that rocket motors of an unheard-of size could be manufactured in mass production. It proved that it was easy to handle many tons of liquid oxygen, it proved that such a gigantic rocket could be controlled. Some of the vexing problems of rocket research, thought to be fairly far in the future and difficult of solution then, were presented in a workable even though not really "perfect" form, like the *Integrationsgerät* and the fuel pump.

All this was acknowledged quickly and unanimously.

But agreement ended when the discussion turned to the military value of V-2. It was not so much the complex of superficial aspects of the case. Everybody knew that V-2 was a not quite finished development which was ready for military purposes to just about the same extent as airplanes were in 1914 (as was later admitted in just those words by Count von Braun), and everybody knew, too, that the German effort of sending 2000 V-2's across the Channel was useless when it happened, as useless as all other German military efforts at that time.

There was no disagreement about those superficial aspects.

But there was, about the underlying principles and their extension into the future. The long-range rocket lacked the ability to carry an impressive payload and could cause damage in only a very restricted area. Even a proximity fuze would not have helped very much. The long-range rocket also lacked accuracy. It could hit nothing smaller than a whole city, and even London, the most sprawling city on earth, was missed by a good number of the rockets. The lack of accuracy, combined with the restricted area of damage, led to enormous numbers of rockets in order to reduce a given target or target area.

That was one point of view and those holding it (as I did)

usually pointed out that V-1 was a much more effective weapon from the point of view of capital expenditure for a given amount of damage. Instead of requiring turbine-driven pumps, complicated controlling gyros, and an *Integrationsgerät*, V-1 needed only a very simple jet impulse duct and a simple robot pilot. Instead of burning $8\frac{1}{2}$ tons of expensive liquid oxygen and alcohol, V-1 needed only one gallon of cheap gasoline or kerosene for each mile of range. Both transported a one-ton warhead, both were equally inaccurate.

Those who defended V-2 as a weapon even at the present stage of development admitted all these advantages of V-1 but claimed that they were blotted out by the simple fact that V-1 is easily interceptable by literally a whole arsenal of counter weapons. But there is nothing anybody could do to stop a falling V-2, and it is more than probable that no really effective counter weapon can be evolved. It might be possible to create some kind of guided missile as a robot interceptor, but it is only too likely that such interceptor missiles could account for only a relatively small percentage of long range rockets.

Then A. V. Cleaver, of De Havilland and of the British Interplanetary Society, suddenly added a new and potent argument in favor of V-2. He pointed out (in the July 19, 1945, issue of *Flight*) that *V-2 might operate more cheaply than a fleet of bombers*. A large bomber can carry eight times as much as a V-2, but it probably costs thirty times as much. It is a most expensive implement to maintain and it requires a flying crew of at least eight men whose training is a large item in the budget. It requires a big ground crew, it needs hangars and airfields with long runways. And it requires a number of auxiliary services, such as the Air-Sea Rescue Service.

Taking all these things, which Cleaver pointed out, into account, it looked as if a bomber would have to fly over a hundred missions in order to deliver 800 one-ton bombs as cheaply as 800 V-2's. We all know that bombers do not fly over a hundred missions as a rule; during the war it was customary to be satisfied if a bombing force sustained losses not surpassing 5 per cent, which means 20 missions per plane as a statistical average. Mass-produced V-2's can certainly compete with that, except that the bombers can have a longer range. And the better the anti-aircraft defense of a city or an installation, the more the balance tends to tilt in favor of V-2.

Of course it should also be mentioned that V-1 as well as V-2 are an all-weather air force which is never grounded just because of bad weather.

But all these arguments pro and con are invalid now; they have all been cut short by the atomic bomb. Even if, in spite of everything that Cleaver said and intimated, V-2 is taken to be a terror weapon if it carries *amatol*, it becomes the final weapon if it carries an atomic bomb. With an atomic warhead V-2 does not need to be accurate. Four or five chance hits in the London area would leave a blob of molten masonry which only by its presence would indicate that it marks the site of a former city. And with atomic warheads, only four or five out of several hundred V-2's would have to go through to accomplish complete destruction. Before the advent of the atomic bomb, arguments about what this or that weapon could or could not do were customary. And they were useful too. With atomic explosives any weapon which can carry an atomic bomb can do anything. And even theoretically it is impossible to stop every one of a salvo of long-distance rockets. The solution of the original arguments is completely unsatisfactory: there is no defense.

The Germans went beyond A-4 in their work. There was something else, labeled A-9 and A-10, which had passed the preliminary experimental stage. But before that can be discussed we have to interest ourselves in some of the theory behind A-4.

Chapter 10:

THE ROCKET INTO COSMIC SPACE

*Alter erit cum Tiphys, et altera quae vehat
Argo Delectos Heroes . . .*

*There shall be another Tiphys and another
Argo to carry Chosen Heroes . . .*

—Virgil (Eclogues IV)

HISTORY, in the shape of the Peenemünde research institute and its product A-4, has seen fit to jump over the first stage of the probable development as it was outlined in the early days of rocket research.

The long-distance rocket exists, the meteorological rocket still remains to be built. That historic leap across the first step does not mean that the first step is now either obsolete or superfluous, or both. But it does mean that an exposition of the things to come can be much more definite, there is now much more certainty and less conjecture in the description of the space rocket, the third step of the original exposition.

Years ago it had been suggested that the long-distance rocket could be used (and presumably with financial success) for the rapid transportation of urgent mail. But this idea, theoretically correct as it is, may be considered dead by now. The accuracy of a long-range mail rocket would be rather poor. Even if it were just one per cent of the distance, that one per cent would amount to a lot of miles in a distance of 2000 miles and up. For transatlantic mail rockets the place of descent would be within a circle at least 70 miles in diameter. Such a high dispersion would necessitate descent on water where the watchers could see over long distances without the obstruction of buildings or of natural formations. Then the rocket would have to be retrieved by motor boat or helicopter and the mail would have to be dispatched to the addresses by ordinary means.

All these complications and difficulties were foreseen then, but in those days such rocket mail was compared to steamer mail and there was an impressive gain in time, some six hours at the most as

compared to about six days. Nowadays the competition would be against transatlantic airplanes and the gain would have to be counted in hours instead of days, not enough to make the venture financially worth while.

And in the present age of atomic fear no country could permit the use of long-distance rocket mail. No radar could tell an approaching innocent mail rocket from an approaching atomic rocket, fired by an ostensibly friendly aggressor from somebody else's territory.

For both these reasons I believe, as I always did, that the future of rocket development will lie mostly in one direction: straight up. And the next logical step after the long-distance war rocket which entered the stage with such surprising suddenness is the long-prophesied space rocket.

First of all it is necessary to define what is meant by the term "space rocket." It is supposed to mean an unmanned rocket, capable of ascending beyond the 400-kilometer level to which our atmosphere extends—in other words a rocket which will penetrate all of our atmosphere (comparatively as thick as a coat of varnish on an 8-inch globe) and progress for some distance into the region of interplanetary space.

And now we have to enter the field of theory.

Supposing we wanted to send a rocket to an altitude several times the height of the atmosphere, say to an altitude of some 800 miles or about 1300 kilometers. How would we go about designing such a rocket, on paper first, so that it can be built afterwards?

Obviously such a rocket would have to have a certain size and would have to be capable of accommodating a certain fuel load. It is also obvious that the rocket itself should be as light as possible and that it should be capable of carrying as much fuel as possible. The rocket will display a certain *ratio* between empty weight and fueled weight. As we'll see soon in the course of the investigation that ratio will turn out to be the most important single concept in rocket science. It has received a specific name: *mass-ratio*.

So far this name has not been used, but we are already familiar with its meaning. In the meteorological rocket described in chapter 7 the mass-ratio was 2:1; the weight of the rocket at the instant of ignition (usually written M_0) was twice as great as the weight of

the empty rocket plus instruments, parachute, etc. This weight, which includes the "pay load," is referred to as final weight and usually written M_1 . In V-2 the mass-ratio was about 3:1.

It hardly needs to be explained that it is the mass-ratio which, other things being equal, determines the altitude to which a rocket will ascend. If you had two rockets of equal take-off weight and alike in every respect except for the fact that one rocket is in itself lighter than the other and therefore holds more fuel the rocket with more fuel will have a longer burning time and consequently rise longer and higher.

The first requirement, no doubt, is a high mass-ratio.

That statement can be countered with the question: how high?

That depends on the fuel you have at your disposal in a somewhat roundabout manner. The type of fuel determines the mass-ratio required for reaching a certain velocity and the velocity determines the height to which the rocket will rise. Therefore, if we want to send a rocket to 1300 kilometers we first have to find out what velocity the rocket requires for that altitude.

Here a rather simple natural law comes to our aid. It states that the velocity of impact *from* a given altitude and the velocity of departure *for* that altitude are equal. If there were no air resistance that law would mean that a bomb dropped from 30,000 feet on an anti-aircraft battery would strike the ground with the same velocity with which a projectile fired against that bomber and capable of climbing to 30,000 feet leaves the muzzle of the gun. Because of air resistance the law does not appear to hold true, in fact air resistance not only slows down the anti aircraft shell very quickly, it also prevents the bomb from attaining a high velocity.

But this does not make the law itself invalid; air resistance is merely a complication which calls for a correction. Unfortunately that correction is rather difficult to make, so for a purely theoretical investigation air resistance might be neglected at first. Our conscience can bear this neglect all the more easily since air resistance corrections are required mainly for the densest strata of the atmosphere, say for the first 15 miles. We can accept the following by simply imagining that we are speaking about an actual altitude of about 15 miles when we say "ground."

Now it is possible to draw up a simple table, listing the impact

velocities from different altitudes. This table looks as follows:

ALTITUDE (kilometers)	VELOCITY OF IMPACT (kilometers per second)
51	1
204	2
458	3
813	4
1274	5

Beyond an impact velocity of about 3 miles per second (about 4.8 km/sec.) the formula used becomes so unreliable that figures do not hold true even approximately. The reason is that gravity decreases with altitude. When taking this factor in account the table ends up with an impact velocity of 11,200 m/sec for a fall from *infinite* altitude.

We notice, in passing, the interesting facts that a fall from twice a given altitude does not produce twice the former impact velocity and that a fall from infinity does not produce an infinite impact velocity. The figure which interests us at the moment is the fourth in the column. A fall from 813 kilometers would result in an impact velocity of 4 kilometers per second, about $2\frac{1}{2}$ miles per second. That is the velocity our rocket would have to attain in order to climb to that altitude.

The next step would be to find out what mass-ratio is needed for that velocity, and here we run into the first minor complication. There is not just one answer to that question, there are many answers to it. Theoretically any figure at all can represent the mass-ratio required for a rocket velocity of $2\frac{1}{2}$ miles per second. The reason is that the answer depends on the velocity of the rocket exhaust. Change the figure for the exhaust velocity and you get a different figure for the mass-ratio. Our dilemma now is this: unless we agree upon an exhaust velocity first we cannot get an answer. But if we do agree on any specific value for the exhaust velocity we get an answer for that specific exhaust velocity only. What we want is a general answer.

The way out of this dilemma is simplicity itself. It consists in using the exhaust velocity, whatever it may be, as a yardstick. To be able to do that we need to know just one thing and that is the mass-ratio required to give to a rocket a velocity equal to its own exhaust velocity. That ratio is clearly always the same. If you have a higher exhaust velocity you'll get a higher rocket velocity. If you

don't have a high exhaust velocity you'll get a low rocket velocity. But whatever the velocities are, the mass-ratio of a rocket which is to attain its own exhaust velocity must be a standard value.

It is customary to call the rocket velocity by the letter v while the exhaust velocity is usually designated by the letter c . Now we can phrase our problem more conveniently by asking: "What is the mass-ratio for $v = c$?"

The answer is 2.72 to 1. A rocket weighing 272 units (pounds, or ounces, or kilograms) at take-off and 100 units when empty will attain a velocity equal to its own exhaust velocity. This figure has been mentioned before (in Chapter 3); it is familiar to any student of mathematics and mathematicians call it e . Its correct value is 2.71828183 . . . ; it is easier to call it 2.72. And it is still easier to call it e .

Fine. So v equals c if the mass-ratio is e , no matter what the value of c is. Now we have a general answer to our problem. But what if c , the exhaust velocity, is not high enough? We need $2\frac{1}{2}$ miles or 4 kilometers for our example. What if there is no fuel that will produce such an exhaust velocity?

It does not matter much, at least on paper, because a rocket can move faster than its own exhaust velocity, provided that it still has some fuel left when it gets to that point. Provided, in other words, that it has a mass-ratio higher than 2.72. We may conclude that there must be a standard mass-ratio for a rocket which will move twice as fast as its own exhaust velocity; a mass-ratio for $v = 2c$. There is, it is the square of e , in figures approximately 7.4. The cube of e is 20.1 and a rocket with that mass-ratio can and will attain thrice its own exhaust velocity.¹

Theoretically you can go on in that manner: e^4 would give you four times the exhaust velocity, e^5 five times the exhaust velocity, and so on. It is as simple as that on paper; the trouble is that engineering practice will probably have to stop at e^3 , if it can go that far at all. Whether a rocket with a mass-ratio of 20:1 can still be

¹ The mass-ratios for rockets which have to obtain only fractions of their own exhaust velocity are derived in a similar manner. For example, if the rocket has to attain half its exhaust velocity the mass-ratio is the square root of e , or 1.64. For a velocity of one-quarter of the exhaust velocity the mass-ratio would have to be 1.29, for one sixth of the exhaust velocity the mass-ratio would have to be 1.18, for one eighth of the exhaust velocity 1.13, and for one tenth of the exhaust velocity 1.10. All these figures probably apply to the various bombardment rockets of the Second World War.

actually built is a problem for prolonged discussion. It might be possible, or it might not. But anything higher than 20:1 is clearly out. It can't be done.

For a rocket like the one we set out to investigate that does not trouble us. We want to go to about 1300 kilometers, a little over three times the height of the atmosphere, and for that we need a velocity of 4 kilometers per second. The exhaust velocity of the small "standard" motors of the V2R was just about 2 kilometers per second and the exhaust velocity of the motor of A-4 was a little over 2 kilometers per second. Therefore we have a case of asking for a velocity equal to twice the exhaust velocity and our mass-ratio, consequently, must be the square of e or about 7.4.

A rocket with an exhaust velocity of 2 kilometers per second and a mass-ratio of 7.4 to 1 would ascend to 1310 kilometers or about 820 miles. It would ascend to 820 miles, that is, if you could cast a spell which creates an airless shaft a quarter of a mile in diameter in which your rocket can climb against the pull of earth's gravity without the unfair interference of air resistance. Or else, if you are not good at casting such spells, you may find a non-miraculous method of transporting your rocket to a height of some 20 miles first. In that case the figures would hold true without the aid of additional miracles.

Before we try to improve upon our theoretical methods we'll pause and consider the question of whether such a mass-ratio of 7.4 to 1 can actually be built and how it could be done. And it is at this point that we realize why those fuel pumps of the A-4 rocket were so important.

Remember the meteorological rocket discussed in chapter 7?

There we had two fuel tanks made of aluminum or magnesium tubing, and we forced the fuels from the tanks into the rocket motor by the simple device of using the pressure of a compressed gas, like nitrogen. That was simple and easy, but it did have a drawback: the whole tank had to be sturdy enough to withstand an internal pressure of some 300 pounds per square inch. Naturally such a tank has to be heavier than a tank which just holds the fuel in the manner in which the tank of an automobile holds the gasoline. However, since the mass-ratio of a meteorological rocket only needs to be of the order of about 2:1, that method, even with this drawback, is usable.

It might still be made to result in a rocket of a mass-ratio of

about 3:1, the same as A-4, provided the whole rocket is small. But to go beyond that you need light tanks which will not be able to stand much internal pressure. Hence it is necessary to provide a method of forcing the fuel into the rocket motor without pressurizing the tanks too much.

That method is the fuel pump.

Goddard realized the need for fuel pumps in one of his early patents, Oberth kept harping on the theme of fuel pumps from the very outset. But it seemed almost impossible to build such a fuel pump. It had to fulfill a whole set of rather exacting demands. It should be able to pump the fuels (one of them a liquid gas) with a delivery pressure in the neighborhood of 300 pounds per square inch. It should pump very large amounts, 50 gallons and more per second. It had to be simple enough in construction to eliminate malfunctioning if at all possible. And it had to be light, very light, since the pumps for both liquids and whatever mechanism drove them had to weigh much less than the saving in tank weight. One redeeming factor was that the pumps had to operate for only short intervals of time, a few minutes at the most.

Because such pumps seemed so difficult, some of the engineers at the *Raketenflugplatz* evolved a wishful pet theory, which said that a sufficiently large rocket motor would not require pumps but would get its fuels from the tanks by suction, provided it had been running for a few seconds under pressure first. One accident seemed to indicate that these hopes might be justified to a certain extent. In the middle of the test run of a large rocket motor the pressure valves snapped shut but the motor continued to run. Doubtless there was a loss of thrust for the remainder of that test run, but doubtless the motor kept on burning. The thrust-measuring device must have been influenced by the accident too; it had stopped registering when the valves clicked shut. (I did not see that test run myself.) This happened during the preparations for the Magdeburg experiment, and there was no time to make deliberate tests.

At Peenemünde they must have learned that their pet theory did not work out in practice. Somebody had to invent pumps for A-4. These pumps are not the last word by any means; the main "childhood disease" that comes to mind is the fact that the turbine needs special auxiliary fuels which, in turn, need tanks to carry

them in, instead of being capable of operating on the alcohol and oxygen which powers the rocket itself.

But these pumps show the way and it is safe to prophesy that it will be possible to build a mass-ratio of 7.4 to 1 with improved pumps. And it is likely that even a mass-ratio of 10:1 might eventually be accomplished. The mass-ratio of 10:1 would result in a rocket velocity of $2.3c$ and the altitude would be, if c is 2 kilometers per second and v consequently 4.6 kilometers per second, about 1600 kilometers or almost precisely 1000 miles.

As far as the mass-ratio for a single rocket goes we may confidently expect to be able to send a rocket to an altitude of 1000 miles in the foreseeable future.

If we want to go higher (and we'll want to) we'll have to concentrate our attention upon another point. We already know by implication that mass-ratio and exhaust velocity can be exchanged to a large extent. If for a given case you would need twice as high a mass-ratio as you can actually build, you can still solve the problem if you succeed in doubling your exhaust velocity. It is the problem of the exhaust velocity at which we have to look next.

The exhaust velocity of a given fuel is limited by the amount of energy imprisoned in that fuel. Alcohol and oxygen in proper proportion cannot produce a higher exhaust velocity than 4180 meters per second. Gasoline and oxygen can produce 4450 meters per second. But these figures are theoretical figures, they cannot be expected to materialize in actual practice. So far the actually obtained exhaust velocities are precisely half of these theoretical figures. With improved rocket motor designs one may hope for exhaust velocities of about 2500 meters (2.5 kilometers) per second from these fuels. Three thousand meters per second might be just barely possible; if that value is ever obtained it will represent the limit for these common fuels.

Still, for an assumed mass-ratio of e^2 that would mean a rocket velocity of 6 kilometers per second instead of 4 and a theoretical altitude of 3820 kilometers instead of "only" 1310 kilometers.

A more powerful fuel is known. It is hydrogen with a theoretical exhaust velocity of 5170 meters per second. Only one isolated experiment with hydrogen has been made so far (by Oberth), and it seemed to indicate that an exhaust velocity of four thousand meters per second may actually be obtained.

But hydrogen is not as ideal a rocket fuel as this figure may lead one to believe. It has quite a number of unpleasant characteristics which are, to say the least, annoying. One of these characteristics is that even the temperature of liquid oxygen is still some 70 degrees Centigrade too warm for liquid hydrogen, which is to say that hydrogen is still colder than oxygen when liquefied and proportionately more difficult to handle and to control. Anything of even approximately normal temperature will set it boiling furiously.

Another drawback is that hydrogen, even when liquid, is very light and consequently bulky. This means larger tanks which, of course, means greater weight. A rocket that will have a nice mass-ratio for heavier fuels will not have that same nice mass-ratio for hydrogen. And to make that factor even worse, hydrogen does not behave quite "properly" in the combustion chamber. It will be necessary to have a considerable hydrogen surplus so that the exhaust consists of water vapor (burned hydrogen) and unburned hydrogen. This, of course, means still bigger and consequently still heavier tanks. As a matter of fact, Oberth decided that hydrogen would not do for rockets at all as long as the rockets were still in the atmosphere. Hydrogen, in short, cannot be counted upon as a rocket fuel right now.

For the more distant future one may speculate on monatomic hydrogen as a rocket fuel. Monatomic hydrogen is hydrogen in which each atom is independent instead of being tied to another hydrogen atom to form a normal hydrogen molecule (H_2). Purely on paper monatomic hydrogen will yield a theoretical exhaust velocity of 21,000 meters per second; actually a little more than half of that might be attainable. So far, however, this is pure speculation; it is not even certain whether monatomic hydrogen could be manufactured and stored in appreciable quantities.

Just to forestall possible false hopes, I wish to point out that high explosives like nitroglycerin, guncotton, or TNT are *far weaker* than gasoline or alcohol. They are destructive by virtue of the rapidity of their combustion; if they could be slowed down to useful speeds they would be inferior fuels. The theoretical exhaust velocity of nitroglycerin is 3880 meters per second, that of dynamite 3300 meters per second, that of picric acid 2600 meters per second. Compare this with the values for alcohol (4180 meters per second) and for gasoline (4450 meters per second).

To repeat, high explosives are weaker than ordinary fuels and

would, therefore, be inferior even if they could be used. The only exception from this rule is the atomic explosive Plutonium (Pu-239) which, in the course of time, slowly changes into the rare uranium isotope U-235. Both these substances hold endless promise for almost everything, and rocket propulsion is no exception.

But the utilization of atomic energy for rocket propulsion will probably take some time. Besides, the whys and wherefores of an atomic-powered rocket could hardly be understood without knowledge of the whys and wherefores of chemical-fuel rockets. For this reason I'll go on with the discussion for some time as if atomic energy did not exist.

For the present and for the near future the most likely rocket fuels are the very ordinary liquids alcohol and gasoline. But there is, there conceivably is, something better than liquid oxygen. Theoretically, at any event, there is something better: liquid ozone.

Ozone, discovered by the same chemist Schönbein, who had that adventure with guncotton mentioned in chapter 4, is a modification of oxygen. Ordinary oxygen has two oxygen atoms per molecule and is called O_2 for that reason. Ozone has three oxygen atoms per molecule, hence is called O_3 . It is, to all intents and purposes, a kind of concentrated oxygen. It has a higher specific gravity—a tank which can hold 6 pounds of liquid oxygen can hold almost 10 pounds of liquid ozone. This alone, as can easily be seen, will increase the mass-ratio, since the tank itself weighs the same, no matter what it contains.

Connected with the higher specific gravity is the fact that liquid ozone does not have to be quite as cold as liquid oxygen to stay a liquid. Liquid oxygen boils at minus 183 degrees Centigrade; liquid ozone boils at minus 119 degrees Centigrade.

As far as tank capacity goes, liquid ozone simply means more oxygen in a given space. As far as the combustion chamber is concerned, liquid ozone means even more. It means more energy and a higher exhaust velocity. Liquid ozone can be formed only if it can absorb energy (719 calories per gram) which may be supplied by ultraviolet radiation, electric discharges, or heat. But when the ozone enters the combustion chamber it reverts to ordinary O_2 , releasing the energy it absorbed before. Alcohol with ozone, for this reason, develops a theoretical exhaust velocity of 4630 meters per second (4180 with oxygen), and hydrogen 5670 meters per second instead of 5170. Burned with ozone alcohol may deliver 3500

meters per second instead of the 3000 meters per second which appeared to be the possible maximum.

But ozone, a dark blue liquid, is unstable. If it gets a bit too warm it may revert to ordinary oxygen with explosive suddenness. This, as the handbook on chemistry puts it, "will be accelerated catalytically by the presence of water, alkalies, metal oxides, metals of the platinum group, organic substances, and chlorine." It is a thoroughly untrustworthy substance.

However, the case is not yet hopeless.

The transformation of ozone into oxygen apparently is not only brought about by catalysts, of which there are many in this particular case, but also seems to take place occasionally without a catalyst around.

The point I am trying to make is that the latter is not absolutely certain. For the simple reason that many different substances *can* serve as catalysts for this particular reaction, it is extremely likely that there *was* a catalyst around every time the reaction took place. It is quite possible—though of course not certain—that liquid ozone which is free of all impurities (at least of those that can act as catalysts) will be stable and reliable. Not enough research has been done on that question yet to permit judgment.

But if it should be found that the number of possible catalysts is so large and so widespread that contamination is impossible to avoid, there is still another hope left. There are not only catalysts, there are also anti-catalysts, substances that prevent the catalysts from making their presence felt. If a reliable anti-catalyst for the ozone reaction could be found, the problem would be solved. Until then ozone in lieu of liquid oxygen is a beautiful but unreliable hope.

Let's see now how far we have progressed.

Fuels: still alcohol or gasoline, with a top exhaust velocity of 3000 meters per second and 500 meters more if ozone can be tamed.

Mass-ratio: about 10:1 as likely top limit, resulting in rocket velocities of 6900 meters per second or (with ozone instead of oxygen) 8000 meters per second. Which would produce altitudes of 6000 kilometers and 12,000 kilometers, respectively. These figures are already such that they are hardly "altitudes" any more but begin to be "distances" in the sense in which we speak of the distance at which a comet passes the earth. They are still very short dis-

tances as far as astronomical distances go, but by the same token they are astronomical distances, even if short ones.

From that fact we can draw the necessary courage to tackle the next problem after the space rocket: the moon rocket. Again the definition of this term should come first. The term will be used for a rocket which is capable of ascending from the earth and of crossing the zone where the gravitational fields of the earth and the moon are of equal strength so that the rocket will not fall back to earth but will fall toward the moon and ultimately crash upon its surface.

It is unavoidable as it is logical that any mention of the moon rocket will remind readers or listeners of Jules Verne's moon gun. The idea of a moon gun is something we have to clear from our path first, a mental exercise which is all the more useful since it will provide us with a great deal of information for the case of the moon rocket.

When Jules Verne wrote his famous novel he based the proceedings on one concept only: the "velocity of liberation," also known as "parabolic velocity," "velocity of escape," or, shorter, "escape velocity." It is the velocity which forms the bottom figure in our table of impact velocities on page 233, reading 11.2 kilometers per second which happens to be almost precisely 7 miles per second. It is the velocity with which a body would strike the earth after a fall from infinity. It is the maximum that the gravitational field of our planet can produce.²

If a body could be endowed with this velocity earth's gravitational might could not call it back. The work required to do this, incidentally, is the same as if that body had to be lifted for the distance of one-half earth diameter from the surface through a gravitational field which remains at surface intensity throughout that distance.

The basic idea of Jules Verne's novel is to fire a projectile from an enormous gun vertically upward with a muzzle velocity of a little over 36,000 feet or about 7 miles per second. While the projectile ascends, gravity, pulling constantly, will reduce its velocity

² Meteorites frequently enter the atmosphere of our planet with a higher velocity than that, but this is not due to attraction. The meteorites have a high velocity of their own which may be added to the orbital velocity of the earth when earth and meteorite run into each other. And the orbital velocity of the earth alone is much higher than the velocity of liberation, amounting to 18.5 miles per second.

steadily. But the projectile would have the enormous velocity-wealth of 36,000 feet per second. Gravity would be able to demand a velocity-interest of 32 feet for every second at first. As the projectile recedes that figure would drop to 31 feet per second, then to 30 feet per second, etc., becoming less and less all the time.

In spite of this steadily decreasing rate of velocity attrition the projectile would have expended virtually all its velocity-wealth after 300,000 seconds. But by that time it would also have reached the distance where the gravitational fields of earth and moon balance each other. If the projectile lacked only a few inches per second of velocity at that point, it would still fall back to earth. But if it still had even a few inches per second of velocity left it would begin to fall toward the moon. After another 50,000 seconds it would crash on the moon, with an impact velocity of about 2 miles per second (the "escape velocity" of the moon) having needed 97 hours and 13 minutes or just about four days for the whole trip.

Because of that duration of four days Jules Verne pointed his gun at a point in the sky where the moon would be four days after the order "fire."

While this fundamental theme for Jules Verne's novel is very nearly correct, things began to go wrong when Jules Verne progressed to engineering detail.

The projectile to be fired at the moon is to be a ball 9 feet in diameter, under the erroneous assumption that a newly constructed telescope would be capable of following the path of a ball that size. Since a ball (later redesigned into a shell) of such size would be far too heavy if solid, it is decided to make it hollow, with walls 1 foot thick. The cannon required for such a projectile is, of course, too large to be built in the usual manner. The barrel, of the arbitrary length of 900 feet, is poured into a well dug for this purpose. Actually that barrel, which constitutes all of the cannon, is only the lining of a barrel with walls of indeterminate thickness, formed by the soil of Florida. An arbitrary amount of guncotton (400,000 pounds) is put into the barrel, filling about 200 feet of it. This is supposed to produce a muzzle velocity of 54,000 feet since the president of the Gun Club, or rather Jules Verne, expects to lose the difference to air resistance. All this, as may be expected, is somewhat vague. Elsewhere in the novel it is stated that air resistance will not be important because the projectile, with its high

speed, will require only a few seconds to traverse the atmosphere.

The latter statement is like saying that a slab of armor plate 3 feet thick cannot very well be expected to stop a 16-inch shell since the shell traverses the distance of 1 yard in a thousandth of a second.

If the experiment had actually been made, the experimenters would have found, to their great surprise, that their ball would have landed 100 feet from the muzzle after rising not much higher. And the shell would have been flattened and partly volatilized. The reason is that Jules Verne, who did worry a little about air resistance in the open air, forgot to think of the resistance encountered in the 700 feet of gun barrel. That column of air, 700 feet high and 9 feet in diameter, could not possibly get out of the way of a projectile moving much faster than sound. It would have to be compressed, and the hollow ball or shell, as later redesigned in the novel, would have found itself between two very hot and enormously powerful pistons: the furiously expanding gases of the gun-cotton underneath and the column of air, heated by compression, above. The passengers, if everything had worked as Verne wanted it to work, would have been spread out into a thin film by the enormous acceleration of the projectile.

But even the shot itself would not have worked. As I stated in chapter 2, a modified moon gun has been computed by Oberth and Valier for their own amusement. The results were as follows:

The projectile must consist of a high-grade steel alloy—for example, tungsten steel—and must be practically solid. Its caliber must be 1200 millimeters (about 48 inches) and its length six times its caliber. The gun must be 3000 feet long and must be built into a mountain near the equator so that the muzzle is at least 16,000 feet above sea level. Before firing, the air has to be exhausted from the barrel and the muzzle has to be closed with a metal lid—padded with rubber around its rim—which is strong enough to resist the air pressure from above. Since the vacuum in the barrel cannot possibly be perfect, there will be a small amount of air left which is then compressed by the moving projectile and which will push the lid off just before the projectile itself reaches the muzzle.

Some years later Count von Pirquet went over the problem again and came to the conclusion that even this improved moon gun would fail to perform fully as required. In the first place, von Pirquet made the mountain 3000 feet higher so that the muzzle of

the gun would be at an elevation close to 20,000 feet. Furthermore, he found that the gases of the propelling charge would not expand rapidly enough if the whole charge were packed at the bottom. He rectified this by attaching a considerable portion of the charge to the bottom of the shell and by furnishing a number of extra firing chambers along the length of the barrel, their mouths leading into the barrel from the side. But even after all this we cannot say whether the gun itself could be built and whether the national budget for an average war would be sufficient to pay for it.

You cannot shoot into space through an atmosphere like the earth's and against a gravitational field like ours. The moon gun on the moon—it would then be an earth gun—working against a lesser gravity and without any perceptible atmosphere would be possible. On earth it cannot work.

While it appears quite impossible to build a moon gun, it is quite likely that a moon rocket could actually be built. In our investigation of the mass-ratio problem we made one rather restraining assumption without specifically mentioning it. Bluntly speaking we assumed that the rocket would stay (and would have to stay) in one piece. Because of that we had to come to the conclusion that a mass-ratio of 10:1 is unlikely to be surpassed.

There are additional possibilities, possibilities which, when properly exploited, will permit still higher mass-ratios.

During the discussion of the meteorological rocket in chapter 7 and during the description of the actual performance of V-2 we have seen that the natural combination of constant thrust and of diminishing rocket weight produces an increase of the acceleration with which the rocket climbs upward. That increase is not at all advantageous if it takes place too early or rather too near the earth where the density of the atmosphere is still considerable. But that increase in acceleration is a decided advantage if it takes place at a high altitude, say after the 10-mile level has been passed. If it were possible to help this increase along beyond the point at which it occurs naturally we could gain a great deal.

That could be accomplished only by increasing the thrust of the rocket motor and since its exhaust velocity is given (it increases too by about 15 per cent in these high altitudes) the motor thrust could be increased only by burning a larger quantity of fuel every second.

This could be accomplished in more than one way. One solution

would be to have a second set of fuel and oxygen lines from the tanks to the motor which would not begin to function until after a calculated number of seconds had elapsed. In a rocket with fuel pumps it might be possible to have the pumps run at a higher speed after some time. Or we might have several sets of fuel tanks in one rocket. The capacity of one such set might be such that it was exhausted when the rocket reached an altitude of 10 or 12 miles. After they were exhausted the motor would draw from the other set which would be equipped with wider fuel lines and larger valves.

It would be an additional improvement if the design could be arranged in such a manner that the first empty set of tanks was dropped when no longer required. (The tanks would, of course, be equipped with parachutes so that they would neither be damaged nor cause damage.) This would improve the mass-ratio further since the rocket would not have to carry the dead weight of the empty tanks all the way up. The higher penetration due to greater weight, so comforting in the meteorological rocket, no longer plays a role in the really rarefied layers beyond 100,000 feet.

The idea of dropping some empty tanks logically leads to the conception of dropping other parts which have become useless and finally to what has become known as "step rocket," a larger rocket serving as a "lower step" for a smaller rocket. This would be the non-miraculous method of transporting a rocket to an altitude of 20 miles. Peenemünde planned such a step rocket for the purpose of shooting to America, but Peenemünde did not invent the idea.

Both Goddard and Oberth had arrived at the principle of the step rocket in their first theoretical studies. Even then the idea was not new; a Belgian patent, granted to Dr. André Bing in 1911, described that invention. You can find pictures and descriptions of step rockets in books on fireworks dating back to 1700 and earlier. The fireworks makers did not do it to gain an especially high altitude, they did it to obtain an impressive display. But the idea was there.

Some reviewers, past and present, have thought that they could visualize the idea of the step rocket for themselves by merely thinking that the step principle is a method of building a rocket which is too large to be built in one piece. Well, it is not as simple as that, which is most fortunate indeed because the real truth is so much better. Nor is it simply a question of having the second step already

at high altitude when it begins to work. To see what really takes place we need a specific example with figures.

For the purpose of our example we'll assume that we can build rockets with a mass-ratio of 10:1 and that we can build a rocket which weighs 1000 pounds when fueled and ready to take off. When empty its weight is assumed to be 100 pounds. Paying no attention to air resistance, we find that this rocket will attain a velocity of $2.3c$. This, of course, would still be an ordinary rocket with a nice high mass-ratio. But then we build two rockets of this mass-ratio, one weighing 800 pounds (80 pounds when empty) and one weighing 200 pounds (20 pounds when empty). The larger rocket will carry the smaller one aloft. The total weight at the take-off is still 1000 pounds.

When the larger rocket which burns first is exhausted, it will have attained a velocity of $1.27c$. The figure is less than the $2.3c$ mentioned because this rocket does not have the full weight ratio of 10:1. It has that weight ratio when considered alone, but it carries the smaller 200-pound rocket and, as far as the performance of the first rocket goes, these 200 pounds are additional dead weight.

To repeat: the larger rocket, carrying the small one but otherwise empty, has attained a velocity of about $1.27c$. Now the smaller rocket starts burning while the empty hulk of the lower step is supposed to drop off. For our private amusement we'll assume first that something goes wrong and that the empty shell of the lower step does *not* drop off, which does not do too much harm since the whole design is such that the smaller rocket can function in spite of this handicap. Since both rockets together have the "over-all" mass-ratio of 10:1 the final result will again be $2.3c$. The imagined mishap, in other words, left the whole performance unchanged so that we might as well have had just one rocket of that mass-ratio.

But then we remedy whatever went wrong and then we get something better. Unhampered by the empty hulk of the large rocket, the small rocket by itself can attain a velocity of $2.3c$. But when it began burning it already had a velocity of $1.27c$ from the efforts of the lower step. As a result its final velocity becomes $1.27 + 2.3 = 3.57c$.

We see that the velocities add up. Whatever the lower step or steps could accomplish serves for the good of the upper step, a

gradual amassing of velocity-fortune over the equivalent of generations.

A single rocket which could attain a velocity of $3.57c$ would have to have a mass-ratio above 30:1, something which probably cannot be built any more. But two rockets, each of a mass-ratio of 10:1, when used as upper and lower steps for each other, will produce what may be called an "ideal mass-ratio" of more than 30:1. And we might be able to add a third step.

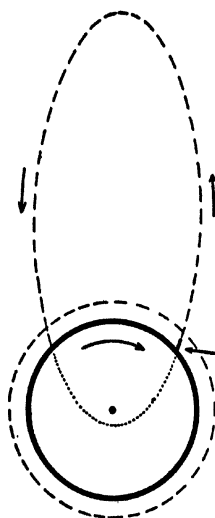
Here we have a way of producing almost incredible mass-ratios. In order to make it effective the lower step of each rocket should be considerably larger than the sum of all the higher steps. In fact the term step rocket should be used only if this condition is fulfilled. If for some reason a lower step is smaller than the upper steps—if it should only be necessary to add a comparatively small amount of velocity to what the upper step can produce by itself—the lower step is no longer called by that name. In such a case Oberth called the lower step *Schubrakete*—Booster Rocket is a good English equivalent. It may be recalled in this connection that I referred to the pseudo first step of *Rheintochter* as a "booster unit."

But the Germans did plan a true step rocket, their "America Rocket." It was a combination of A-9 plus A-10. A-9 was simply an A-4 rocket equipped with highly swept-back wings. These wings were not supposed to assist the ascent of the A-4 rocket to which they were attached, the idea was that they would convert the *empty* A-9 into a high-velocity glider. A-10 was a lower step for A-9, with a take-off weight of 85 tons! The empty A-10 was to be recovered by parachutes; it would have landed somewhere in France or in Spain, while A-9 would have reached the mainland of North America about 20 minutes after take-off of the combined A-9 + A-10.

If used alone A-9 would have had a range of about 300 miles, about a hundred miles more than A-4 without the wings.

Wings or not, an A-4 rocket, with an 85-ton A-10 rocket as a lower step, would have penetrated into interplanetary space, but it would have returned to earth eventually. Its path, whether it had departed vertically or at a lesser angle, would have varied in appearance, but it would always have been the same geometrical figure: it would always and invariably have been an ellipse, with the center of the earth in one of its two focal points.

Any space rocket departing from earth has no choice but to obey



33. Orbit of a Space Rocket.

The orbit of a space rocket, although released vertically, would assume this form. The trajectory would be an ellipse with the center of the earth in one of its focal points. Save for the drift in the troposphere during the return, the trajectory could be calculated with great accuracy. The whole orbit would be traversed in "free fall," and only a short section of the ascent (marked by an arrow pointing to it) would be under power.

Kepler's laws with respect to the earth as a planet obeys these laws with respect to the sun. The path is, therefore, referred to as a Keplerian ellipse. (Fig. 33.) The rocket travels almost the whole of that Keplerian ellipse, except for the section below the surface of the earth. This same orbit, incidentally, applies to any artillery shell. The so-called trajectory of a projectile is simply the part of a very short

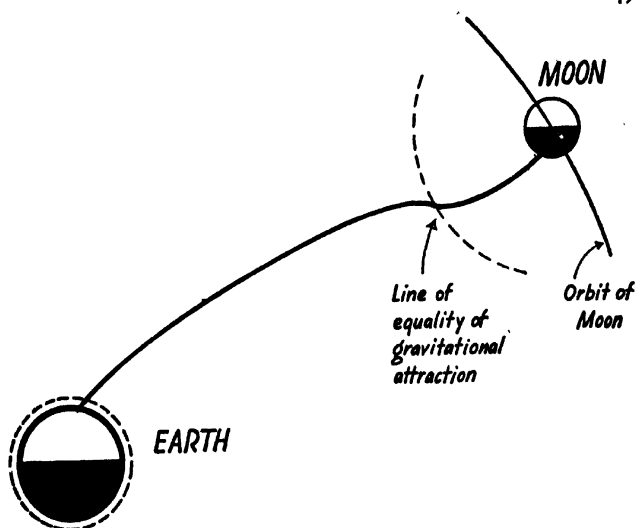
Keplerian ellipse that is above ground. In this case it is only a very short section of the complete ellipse, not a parabola as most instruction booklets state for the sake of simplification.

Most of the ascending half of the Keplerian ellipse would be traversed in "free ascent" after a few minutes of burning time. The gravitation of the earth gradually kills the upward momentum of the rocket until it comes to a standstill. Then it begins to fall back.

If we imagine that ellipse to be more and more elongated, the point farthest from the earth—technically known as the *apogee*—may fall beyond that imaginary line where the gravitational influences of the earth and the moon are equal. If that happens, if the *apogee* falls beyond that line, the rocket will not return. It will fall toward the moon.

The path described by it is shown in Fig. 34; it is a curve shaped somewhat like a capital "S" which somebody tried to straighten out by pulling at both ends without very noticeable success. The curve consists of two sections of two different Keplerian ellipses joined together, one section belonging to an ellipse with its focal point in the center of the earth, the other section belonging to an ellipse with its focal point in the center of the moon.

That, then, would be the moon rocket.



34. Orbit of an Unmanned Rocket to the Moon.

The earth and the moon are drawn to scale, but should be eight times as far apart. The orbit would then look like a straight line. The rocket would need close to one hundred hours for the trip, but only seven or eight minutes would be under power.

Naturally it would crash on the moon and one of Dr. Goddard's early suggestions was to do just that, putting a "pay load" of flash-light powder into the nose of the rocket so as to create a flash which could be seen in a telescope and thus prove that the rocket actually did reach the moon.

But there are disadvantages to this idea. Oberth stated repeatedly that the only mistake he had been able to find in Dr. Goddard's first publication was the underestimation of the amount of flash powder required. I don't intend to mix into the discussion since I dislike the idea of a single flash that may be missed merely because the observatories that are favorably situated for the observation of the flash are having a period of bad weather or poor visibility.

If the rocket "crawled" across the line of equal gravitational attraction, it would strike the surface of the moon with a velocity of just about 2 miles per second, the "velocity of liberation" for the

moon. If it had some velocity left when crossing the line, its velocity of impact would be proportionately higher. At any event it would be considerable and cause the formation of a new small "crater." This tendency can be increased considerably if we substituted some 10 pounds of *tetryl* (which is more powerful than TNT) for the flashlight powder. That would cause a permanent marking which could be searched for at leisure.

It can be made even more conspicuous if only half a pound of *tetryl* were used (it would be set off by the impact) and if the other 9½ pounds were plaster of Paris or a similar fine white powder which would be scattered over a visible area by the explosion. Since the surface of the moon is rather dark, on the average as dark as darkish terrestrial rocks or lava, the white powder, no matter how thinly spread, would show in an unmistakable manner. It would look bright when seen from the earth even if it were so sparsely spread that it would be unnoticeable to a man walking over that area.

The mass-ratio required for the experiment would be high, as can be seen from the following table:

ASSUMED EXHAUST VELOCITY (meters per second)	MASS-RATIO REQUIRED
3,000	237
4,000	60
5,000	26
10,000	5.5

Clearly only the last two figures of this table are debatable from the engineering point of view. Nobody could (or would) attempt a mass-ratio of 237:1 or 60:1, but 26:1 is within the realm of possibility for a two-step rocket and 5.5:1 could even be built as a single rocket.

But that implies an exhaust velocity of 10,000 meters per second, close to 33,000 feet per second. No known fuel could produce that exhaust velocity, unless monatomic hydrogen became feasible as a rocket fuel. Atomic energy, of course, could produce even more than that, once we had learned how to handle it for that purpose.

Five thousand meters per second might be obtained with hydrogen and ozone. These fuels make a two-step moon rocket a feasible undertaking.

We may go one step further now.

35. *The Trip around the Moon.*
The final landing on earth is accomplished by means of "braking ellipses."

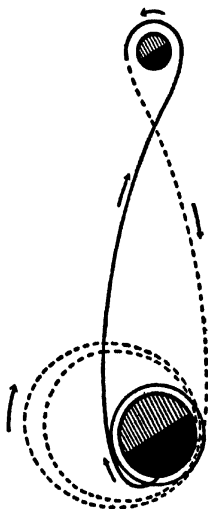
If we increase the mass-ratio still more, we may get a rocket to go around the moon and fall back to the earth, either in a straight ellipse with an apogee considerably beyond the orbit of the moon or in the somewhat preferable curve shown on Fig. 35. In that case, we might equip the rocket with automatic film cameras and get pictures of the "other side" of the moon.

Yes, but. . . .

Such a trip would be a rather complicated maneuver, requiring delicate control. Theoretically it might be accomplished by throwing the rocket into just the proper orbit with the proper velocity at the proper time. Or else, if you are not quite so punctilious in the beginning, you can correct the mistakes later on, say by a set of robot pilots hooked up with "electric eyes" which perform some minor feats of celestial navigation. The first method, Oberth estimated, would imply that you master the exhaust velocity within a range of less than a foot per second, which is obviously impossible. The second method would require a great deal of fairly delicate machinery, weighing, at a guess, some 1200 pounds or more.

The remedy obviously consists in finding a robot pilot which would weigh less than 1200 pounds, say between 150 and 200. There is such a lightweight "robot pilot" in existence that is also fairly rugged within reasonable limits and which has the additional advantage of being very versatile and adaptable. Its designation is *Homo sapiens*.

This "remedy," which eventually will become necessary, automatically alters the designation of the rocket. The space rocket which crashes on the moon is still just a space rocket. The space rocket which needs a human pilot because of the necessity of a few adjustments of velocity and direction—but mainly for the purpose of determining the need for these adjustments—is a spaceship.



Chapter 11:

THE SPACESHIP

*Illi robur et æs triplex
Circa pectus erat, qui fragilem truci
Commissit pelago ratem primus.*

*Oak and brass of triple fold
Encompassed sure the heart, which first made bold
To the raging sea to trust a fragile bark.
—Quintus Horatius Flaccus (Odes I).*

NOBODY ever doubted the meteorological rocket. And after V-2 everybody became quite willing to grant the space rocket. And after the problem has been explained almost everybody will concede the unmanned moon rocket. But when it comes to spaceships, all heads begin to shake and objections begin to come forth in a thick stream.

How are you going to land? How are you going to return? What are you going to use for a fuel? How do you expect the pilot to stand the strain? What kind of food are you going to carry? How about water for drinking and washing? What about oxygen for breathing and fuel for heating the cabin?

Occasionally these questions are not uttered as questions but take the form of a plain statement, such as can be found in the book *Consider the Heavens* by Forest Ray Moulton, which says:

It must be stated that there is not the slightest possibility of such a journey. There is not in sight any source of energy that would be a fair start toward that which would be necessary to get us beyond the gravitative control of the earth. There is no theory that would guide us through interplanetary space to another world even if we could control our departure from the earth; there is no means of carrying the large amount of oxygen, water and food that would be necessary for such a long journey; and there is no known way of easing our ether ship down on the surface of another world, if we could get there.¹

And there is no reason to make any of these statements!

¹ Written in 1935, more than ten years after Oberth and Hohmann furnished that theory which Dr. Moulton finds lacking. These sentences have also been quoted with glee by Mary Proctor in one of her books.

Going into a discussion of such questions as water and food, oxygen and heat are obviously useless until we have a clear idea of the requirements, and these hinge without exception on one factor—time. Before we can say anything about the possibility of a journey into space, we have to know how long it will last.

Fortunately this is something we can predict. We can say, for example, that a trip to Venus and back would last two years, one month, and a few days. Nor is this prediction idle.

I admit that, when seen at first glance, a discussion of a trip to Venus—or to Mars, or to the moon, for that matter—at the present stage of development in rocket research may look as if it were comparable to a conversation about transatlantic flights between Wilbur and Orville Wright on the day after the first hop at Kitty Hawk. But there are differences.

A transatlantic flight depends essentially on the steady generation of so and so many horsepower for so and so many hours. The motors have to maintain their power output to keep the plane in the air and to overcome air resistance. A trip into space depends essentially on the generation of a particular high velocity which does not need constant fuel expenditure to be maintained to the required degree. Once that velocity has been attained—and that must be done in a matter of several minutes—the motors keep silent, no matter how long the trip itself may last. The theory of space travel does not operate with “quantities of work” but with “quantities of motion.”

I do not say that the one or the other is easier to accomplish; I am just pointing out the difference. And a transatlantic flight leads through atmosphere, through weather, a proverbially unreliable commodity. A trip into or through interplanetary space has nothing at all to do with weather. It leads through the gravitational fields of various celestial bodies, a thoroughly reliable proposition.

There are very many things about spaceships which nobody knows at the present moment, which could not even be determined at the present moment, no matter what efforts were spent in this direction. But the orbits those spaceships, once they exist, will have to travel are not among them. These routes are not arbitrary by any means and because of that—and because it is essentially a problem in astronomy—they can be predicted now. Nor is that prediction of the kind that says that the next President will be a Republican if he is not a Democrat. The prediction is rather of

the type of those you find in the calendar on those pages which state when the sun will rise and set on a certain day, when the moon will be full and when an eclipse is due to occur and where it will be visible—in short, astronomical information about the future.

But we were talking about substituting a live pilot for a robot pilot. The case in question was the moon rocket. And while I am postponing everything that has to do with the bodily welfare of the pilot, there is one point that has to be taken up at once because it also influences the technical requirements. That is the question of acceleration.

Plain speed has no influence at all on the human body. We are traveling around the sun at a rate of almost 20 miles per second, but we don't even feel it. We are traveling with the sun with a similar velocity in a direction which is almost at right angles to the direction of the earth's movement. It took us hundreds of years even to find it. We are traveling in still another direction, with much smaller velocity, due to the rotation of the earth. We are probably traveling at a very high rate with our whole galaxy.

Plain speed does not matter at all.

What does matter are changes in speed, called acceleration and deceleration. The proper question is, therefore, what amount of acceleration the human body can stand without being harmed. The war has provided an enormous amount of material because every airplane pilot who pulls out of a dive or makes a sharp turn is subjected to a strain which, although caused by centrifugal force in the majority of the cases, is precisely the same as would be caused by acceleration or deceleration in a straight line.

We know that the pilot should not surpass 6g, that he should not surpass 4g without training. We know that some people stand the strain better than others, though there are few outward signs that tell us who will and who won't. Winkler put a man on a new electric carrousel which he rented for this experiment and let it run at full speed for almost ten minutes, causing the sole passenger to stand a strain of 4g for almost this length of time. When he came out he was dizzy because it had been a rotary motion, but he felt all right otherwise.

It can be concluded, therefore, that an acceleration of 4g (or 3g effective) could be used. In fact, Oberth suggested that the pilot be tested several times by means of a large centrifuge producing the equivalent of this acceleration; moreover, the instru-

ment could also be used for practice. There is little doubt that the strain will be endured best in a supine position, but it must not be imagined that it will feel as if three times the weight of the body were piled on top of his body. The tissues near the back will take more of the strain and it will probably feel as if about half the expected weight were resting on the body. These things can be investigated in detail when required; so far there is no reason to believe that an acceleration of $4g$ for a period of ten minutes (which is the maximum possible duration of ascent under power) will prove harmful to a healthy person.

It may be well to mention at this point that it would not matter greatly if the pilot did "black out" during the period of initial acceleration. Just because of that possibility, the spaceship has to be designed for automatic performance during this period anyway. This would not be difficult at all, and the pilot is not required for the ascent; he is needed for observations and correction later on.

You are at liberty to have some doubts about these points. The discussion's main purpose was to find out what acceleration should be inserted in the equations for a first survey of the requirements.

Although I am getting ahead of the proper sequence of discussion, at this point I feel obliged to give the figures for the moonship now. The figures I am going to present are Oberth's and they can be found on page 376 of *Wege zur Raumschiffahrt*. Needless to say, the moon voyage has been calculated by others too, but the divergence between the results of various computers is comparatively small so that one set of figures will do.

Oberth assumed that the trip from the earth to the moon would be made by acquiring just enough momentum to pass the line of equal attraction. Then it would be necessary, of course, to stop the velocity of about 2 miles per second which is acquired by the ship when falling toward the moon. It can be stopped only by turning the ship around in the direction of its fall and by using the rocket motors to reduce the falling speed so that the ship touches the surface of the moon with the velocity reduced to zero. After some time the pilot would wish to return and has to take off from the moon, again by using the rocket motors. Fuel for all these maneuvers would have to be brought from earth, of course. But the landing on earth can be accomplished without using fuel at all, at least theoretically. Actually a small amount of rocket firing may be required.

The example, therefore, looks like this:

MANEUVER	"IDEAL" VELOCITY REQUIRED FOR THIS MANEUVER (meters per second)
(1) Take-off from the earth	11,200
(2) Reduction of velocity of arrival to zero	3,030
(3) Losses sustained during execution of maneuver No. 2 (owing to too much caution)	870
(4) Take-off from the moon	3,030
(5) Allowance for corrections and mistakes	1,000
Total	19,130

This total, assuming the exhaust velocity to be 4000 meters per second (hydrogen and oxygen), represents a mass-ratio of 134 to 1. The periods of acceleration are as follows: for maneuvers (1) and (2) eight and nine minutes respectively—the long period of nine minutes is what causes the losses listed under (3); for maneuver (4) ninety seconds. Maneuver (5) is, of course, indeterminate, taking only a few seconds at a time.

The trip to the moon would take around ninety-eight hours. The return trip would take the same time plus an estimated twenty-four hours for the landing on earth plus whatever time the pilot spends on the moon. Either way the trip can be started at almost any time. There is not much reason to wait for an especially opportune time unless the pilot wishes to land at a certain spot on the moon, say near crater Copernicus, at the time of sunrise for Copernicus.

The mass-ratio of 134 to 1 would require at least a three-step rocket; the venture is clearly much farther in the future than the plain moon rocket.² If you imagine that the shape of the moonship is that of a huge artillery projectile, which seems to be the most likely shape, it would tower to about one third of the height of the Empire State Building.

The mass-ratio of 134 to 1 is unpleasantly high, but it is certainly closer to the realm of possibility than the fantastic figures that were computed several years ago by the Canadian astronomer Dr. J. W. Campbell of the University of Alberta. Dr. Campbell stated that a moonship would have to be about as massive as Mt. Everest, that its mass would be such that it could form a ball 5 miles in diameter. Dr. Campbell's mathematics were, of course, correct, but

² That is, if a slow and tedious development is taken for granted. Actually such developments have a habit of progressing in sudden spurts.

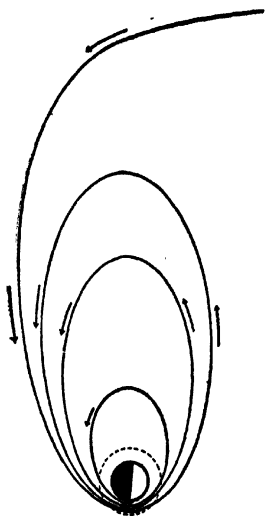
he made the wrong assumptions. The returning ship, he assumed, would weigh 500 tons, and the exhaust velocity was estimated, if I remember correctly, at less than 1 mile per second. With these assumptions you do arrive at such figures. But these figures do not prove that the problem cannot be solved. They only prove that the problem cannot be solved for a 500-ton ship and an exhaust velocity of some 3000 feet or about 1000 meters per second.

As a matter of fact Oberth even exaggerated a bit with his mass-ratio of 134 to 1 for an exhaust velocity of 4000 meters per second. He deliberately ignored the fact that the gravitational attractions of the moon and of the earth compensate each other to a slight extent all along the way. Taking this into account you arrive at a mass-ratio of 120 to 1 for an exhaust velocity of 4000 meters per second and of 44 to 1 for an exhaust velocity of 5000 meters per second.

The mass-ratio for the rocket around the moon, without landing there, will come out to about 80 to 1 for an exhaust velocity of 4000 meters per second and about 55 to 1 for an exhaust velocity of 5000 meters per second. If we assume the higher exhaust velocity, a two-step rocket would be sufficient to accomplish this trip which, if nothing else, would yield photographs of the unknown "other side" of the moon, photographs of the sun as it appears without the interference of the earth's atmosphere, and photographs of the earth itself. The latter two things, however, could also be accomplished by the unmanned space rocket.

The returning moonship, naturally, has to land. If this has to be done by reducing the falling speed of the ship—again that famous velocity of liberation of 11,200 meters or 7 miles per second—all the mass-ratios mentioned would have to be multiplied by about thirty and would, in consequence, loom even more forbidding. But rocket power, fortunately, is not needed for the landing on earth. In this case the atmosphere, which generally causes so much trouble, proves to be useful.

The returning moonship, audiences have been informed by careful characters time and again, would burn up in the atmosphere just as a meteorite burns up. There are some differences, however. In the first place, the moonship returns with about 7 miles per second, about one fifth of the velocity with which the average meteorite runs into the earth. The heating is the result of the compression of air molecules in the path of the meteorite (or ship),



36. "Braking Ellipses."

The drawing is to scale, except that the atmosphere (broken circle) is about four times too deep. The length of the directional arrows indicates the velocity.

and the compression takes place in a cylindrical space having the same diameter as the entering body. Obviously it makes a great difference whether the path, the "cylinder," is 1 or 5 miles in length for a given interval of time. And even the meteorites are not heated up all at once. The outermost fringes of the atmosphere prove too tenuous for that even at high cosmic velocities.

Still, the moonship *would* be heated to incandescence if it entered the atmosphere vertically. Consequently the theory requires that it doesn't.

The pilot of the returning moonship will see to it that his vessel misses the earth by, say, 250 miles. The actual figure may be a little more or a little less—at present we lack the precise data needed for proper calculation, but these data will be furnished by the larger types of meteorological rockets. The idea is, at any event, that the ship *grazes* the fringes of the atmosphere. It will shoot out of the atmosphere again, but with reduced speed. After the first grazing its velocity will be below the velocity of liberation; the ship is no longer independent, but has become another satellite of the earth. That satellite travels around the earth in an elliptical orbit, one of its focal points coinciding with the center of the earth as usual. The *apogee* of that orbit is somewhere out in space and does not interest us very much; the decisive point is that the *perigee*^{*} is just inside the atmosphere. When the ship returns to its *perigee*, it is slowed down again. Again it leaves the atmosphere, and again its speed is reduced. The ellipse is smaller now, the *apogee* is closer to earth, but the *perigee* is still at about the same

* The point of the orbit which is closest to the earth.

altitude above the ground, probably only some 10 or 15 miles lower.

The fourth grazing is likely to reduce the velocity to such an extent that the ship does not leave the atmosphere any more. It now spirals down and finally lands by means of a large parachute. (Fig. 36.)

Russian and German rocket literature is full of discussions of this landing maneuver. The velocities at each point have been computed and for a time a heated discussion raged on whether an additional parachute should be used for the first two grazings or not. This is one of the questions that simply cannot be decided at present. We have to know a lot more about the density and composition of the atmosphere at these altitudes before we can really settle down to a detailed computation. But the maneuver itself has survived all criticism. Essentially that is the way the landing can be accomplished without large fuel expenditure. It would take about twenty-four hours from the first grazing to the final landing.

It may be useful to say something about gravity at this point.

The whole problem is a fight against gravity and in all these discussions the fight against gravity has been waged on the basis of brute force. The gravitational power of the earth amounts to a velocity of 7 miles per second. We answer with an investigation of methods supposed to create a velocity of 7 and a fraction miles per second. The moon can produce 2 miles per second. We get ready to fight back with 2.1 miles per second.

But those novelists who wrote about voyages to the moon and to other planets during the latter part of the nineteenth century did, as a rule, forego brute force in the fight with gravity. They used subtler means, substances which were not affected by gravity, substances which produced gravitational shadows, like Mr. Wells' *Cavorite*. Is there no possibility that such a substance may be found and utilized before rocket research has progressed to exhaust velocities of 5000 meters per second and to step rockets with a combined mass-ratio of 60 or even 80 to 1?

There are two answers to that question. One is not greatly in favor of that solution. The other is against such a solution.

Just what—to begin with the first answer—do we know about gravity? We do know that gravity decreases with the square of the distance which is the result of the geometrical fact that the area of a sphere is proportional to the square of its radius. This, then, is

not a special gravitative phenomenon and we know, as a matter of fact, that other natural phenomena work in the same manner—for example, light. To know this fact is useful enough; all ballistic and astronomical calculations are based on it and they work out nicely. As far as those disciplines are concerned, no knowledge of the nature of gravity is needed. All we have to know is its general behavior and its intensity at a given point. And we know that.

Otherwise we mainly know what gravity does *not* do. It does *not* change with the nature of the matter involved. It does *not* change with temperature. It is *not* influenced by light or darkness, by electricity or magnetism, by ultra-violet rays, radio or X-rays. There is *no* way of screening it. Small wonder that Dr. Paul R. Heyl of the National Bureau of Standards called it an “intractable phenomenon” in the *Scientific Monthly* (August 1938), and continued:

Gravitation appears to be a function of nothing but the masses involved and their space co-ordinates. As to all other properties the evidence is negative, in most cases of a high degree of precision, reaching a few parts in a billion. The cause of gravitation is hidden in a protective armor on which there is not even a projection upon which to hang a hypothesis.

As may be expected under these circumstances, all so-called “explanations” of gravity suffer from the common defect that they don’t work. They all try to account for some of the observed facts by neglecting others or even by neglecting the very consequences arising from the explanation itself. Or else they try to explain the observed facts by explaining them away.

What may be called the “classic” explanation is the one Le Sage of Geneva proposed in 1750. According to him the whole universe was filled with “ultra-mundane corpuscles” moving at high speeds and exerting a steady pressure on the surfaces of all bodies, pressing, for example, humans to the surface of the earth. The obvious present-day answer is to inquire about the heat generated by the impact of the corpuscles, but in 1750, when Le Sage advanced his hypothesis, the law of the conservation of energy was still to be discovered.

The general idea of the Le Sage hypothesis remained a favorite with gravity explainers for a large number of decades. Later elaborations stated that the corpuscles, of course, penetrate all solid bodies, but that they lose some speed while doing so. For this

reason the push from below (at the surface of the earth) does not quite match the push from above, the difference being called "attraction." Again it does not work because of the law of the conservation of energy. And none of all these theories—by now the Le Sage hypothesis has been advanced about fifty times, each time as a "new" explanation of gravity—can be true because a screening effect would invariably result and it should be measurable. If there were a screening effect, the moons of Jupiter would betray its presence. The actual behavior of the moons shows that no screening exists.

When Albert Einstein became interested in this problem he looked about for a similar untractable phenomenon and found it, inertia, especially in the form of centrifugal force. An observer in a rotating circular room, he said, would find himself in a kind of gravitational field turned inside out, forcing him away from the center and becoming more powerful with distance. In that case the observer would know what is happening to him. He would not look to the center or to the rim of the room for the "origin" of the force, but would know that it originated in the objects themselves and that no screening of any kind can be expected.

Einstein then proceeded to say that a "gravitational field is equivalent to an inertial field produced by a suitable change of co-ordinates." To the layman he then promptly disappeared from view in a forest of equations.

His idea is usually explained by comparing matter in space to stones forming cusps in the otherwise flat surface of a frozen lake. Another stone set in motion on that surface which is, by definition, frictionless, would follow a straight line in a given direction until it grazed one of these cusps. Then it would continue in an altered direction. If it got fairly deep into the cusp it would not leave again at all but would revolve around the larger stone. That would look like gravity, being the effect of a three-dimensional cusp in a two-dimensional world. Similarly, popularizers used to state sonorously, real gravity is the cusp made by matter in four-dimensional space—which was neither understandable nor a precise rendering of Einstein's equations.

Actually we have as little reason to believe in four-dimensional space (or in the expanding universe, for that matter) as we have to believe in the two-dimensional world which was assumed to explain four-dimensional space. Higher and lower dimensions have

a certain *raison d'être* in equations on paper but must not be taken literally. Recent astronomical evidence seems to indicate that this idea is as much a blind alley as the Le Sage hypothesis, although for other reasons.

When Aristotle was confronted with the same problem he "explained" it by ascribing the "property of heaviness" to matter. We still have to do the same—gravity seems to be the most fundamental property of matter. And therefore it is practically impossible even to imagine a gravity screen.

This is what I meant in saying that the first answer to the question about gravity screens is not greatly in favor of such a device. The second answer is even more devastating.

If we did have a substance like *cavorite*, it would be useless. The point is this: speaking in terms of physics we live under a certain gravitational potential at the surface of the earth. If we go away from earth we arrive gradually at lesser potentials until the potential finally becomes zero, at an infinite distance from the earth.⁴

To lift 1 kilogram (2.2 pounds) to a height of 1 meter (40 inches) under normal gravity at the surface of earth we have to expend a certain energy which has received the logical name of kilogram-meter and which is used as a unit for measurement. To lift 1 kilogram to the zero potential (to an infinite distance) requires 6,378,000 kilogram-meters, and the gravitational potential of the earth is expressed by that figure.

Cavorite is supposed to create the zero potential. Consequently a man who steps onto a sheet of *cavorite* has to overcome the whole gravitational potential of earth. Supposing he weighs 165 pounds or 75 kilograms. His muscles have to produce a mere 6,378,000 times 75 kilogram-meters for this purpose. It does not matter that he walks only one step. Distance is unimportant; it is the difference in potential that counts.

Now this puts the lucky inventor of *cavorite* in a very curious predicament. Either his muscles are not powerful enough to enable him to enter his spaceship, in which case the marvellous invention is wasted because he cannot use it, or else his muscles are powerful

⁴ It is a deeply ingrained popular misconception that the "gravitational zone" of the earth is somehow limited in extent. This belief makes as little sense as, for example, the belief that a star shines only to a certain distance. What actually happens is that the light of a star may become too faint to be seen if the distance is too large. Similarly a gravitational field may become too faint to be noticeable.

enough for the task, in which case the invention is useless too, but for another reason: the inventor would not need the ship because he could jump to the moon directly!

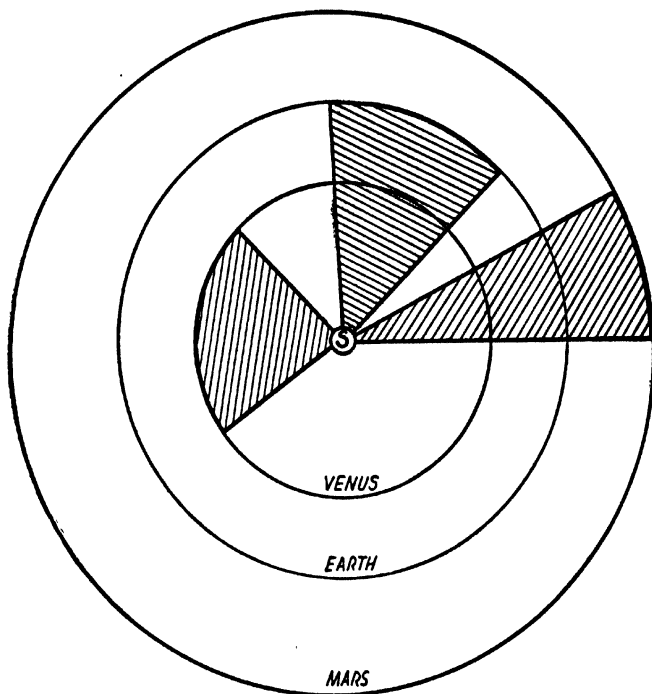
After this interlude we can return to rocket theory with the comforting knowledge that there is no other way of conquering gravity or space. It can be done only by superior force.

We are not yet finished with the theory of interplanetary travel merely because we have discussed the fundamentals of the moon rocket and of the moonship. The moonship is not the whole theory. In fact it is only a special case, a footnote to the theory itself. It is in a subclass of its own because the moon trip pays no attention to the gravitational influence of the sun and to the orbital motion of the earth. Not that the attraction of the sun is unnoticeable at our distance of 93,000,000 miles. It is extremely powerful, but it does not matter since the earth, the moon, and the ship are all subjected to it in the same manner. They are on the same potential of the sun's gravitational field. With regard to the sun all three move with about the same velocity and within narrow limits in the same direction, and because of that the presence of the sun can be disregarded.

An everyday example may make this clear. The straight ascent of a space rocket with an immediate return to earth is like getting up from your seat in a railroad car, going to the window, and coming back. The ascent with a subsequent fall to the moon is like going to another car in the same train. For all these restricted movements it does not matter whether the train is standing still or is traveling at full speed because your seat, the window, and the next car all move with the same speed. But setting out for Venus or Mars means leaving the train and then the speed of the train becomes an important consideration.

The planets of our solar system all move in the same direction around the sun. They also move in almost the same plane; not quite the same plane, but with differences which are not large compared to the enormous size of the whole. Only the orbits of some comets are tilted at a high angle.

But the planets do not move with the same speed; the inner planets are faster by far (Fig. 37). They need the higher velocities to stay in their orbits—to counterbalance the more powerful attrac-



37. *The Movements of Venus, Earth, and Mars during a Fifty-Day Period.*
(Cf. Fig. 2.)

tion of the sun. The whole may be visualized as a whirlpool with sloping sides, the sun being in the center at the very deepest point. The innermost sections rotate at the highest speed, at some distance from the center the speed of rotation is perceptibly slower, while the outer portions, where the whirlpool slopes least, move rather slowly. At each point the speed of rotation is just sufficient to counteract the attraction of the sun, to prevent the bodies that are at that point from sliding down toward the center.

Actually the solar system is flat. The sloping whirlpool is just a device to visualize the action of the sun's attraction.

If a body moving in one of the outer slow parts were suddenly slowed down still more by an outward force, it would slide toward the center. Gaining speed while sliding down it might acquire a

new balance, but the important point right now is that it would be drawn toward the center if it lost some of its normal speed. Conversely one of the faster bodies, pushed to a still higher speed by an outside force, would move outward, overcoming the attraction of the central body.

This picture can be applied to actual conditions in the solar system with little alteration. We'll say that we have a large rocket, capable of attaining considerable velocity of its own, and we'll let it take off from earth. The result would depend on the time of day. If the rocket takes off at such a time that its own speed is added to the speed of the earth in its orbit, it will have more speed than is required to counteract the gravitational attraction of the sun at our distance. The rocket would drift outward in the solar system, climbing against the gravity of the sun. Naturally that gravity would gradually reduce its "surplus" speed, so that there would come a point when the rocket would no longer recede from the sun. If the rocket took off at a time of the day when its speed would subtract from the orbital speed of the earth—as seen from the sun—it would not have enough speed to counterbalance the sun's attraction. It would drift inward in the solar system, approaching the sun. In this case the sun's attraction would increase its speed so that, at one point, the sun itself will have made up for the "deficiency."

That rocket would approach either the orbit of Mars or the orbit of Venus, depending simply on the question of whether its own speed were added to or subtracted from the orbital speed of the earth.

The movements in either case would again be Keplerian ellipses, but this time the focal point of the ellipse would be the center of the sun. The rocket would move along an ellipse which touches the orbit of the earth at one end, and the other end would be elsewhere in space, either outside or inside the orbit of earth. This is general astronomy. There are comets and minor planets which have such orbits—elongated orbits that touch or cross one or several planetary orbits.

The application of this general astronomical knowledge is a question of timing and a question of dosing. It is clear now what a spaceship would have to do to go to Mars: it would have to add its own velocity to that of the earth. Then it would drift outward in the solar system until the orbit of Mars is reached. But the goal

is, after all, not the *orbit* of Mars, but the planet itself. It is a question of timing to arrive at a given point of the orbit of Mars when the plane itself is in that point too.

If the timing is important the dosing is even more so.

If the spaceship added too much speed to the orbital speed of the earth, it might acquire the tendency to drift across the orbit of Mars instead of just to the orbit of Mars. In such a case its own orbit and that of Mars would cross. If it had just enough speed to drift to the orbit of Mars, the two orbits would only touch.

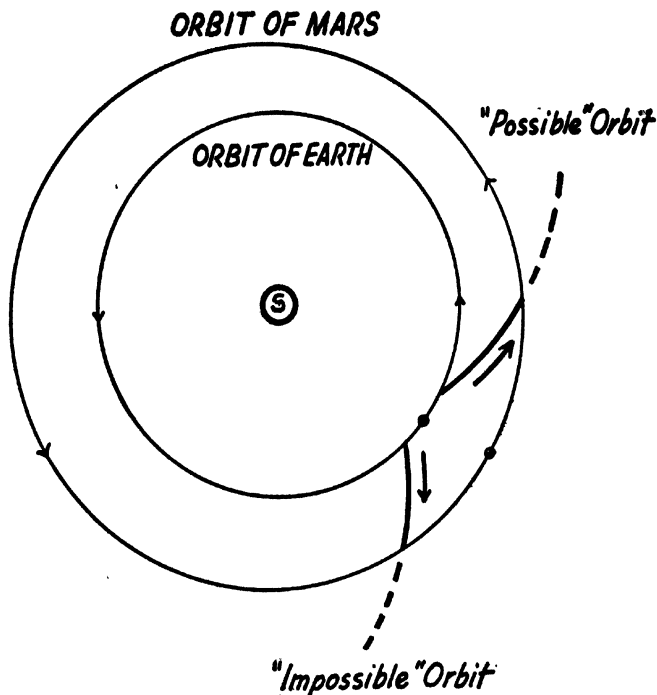
That is the difference between economical and uneconomical orbits. If the orbits of ship and planet *touch*, both move around the sun in precisely the same direction, although not quite with the same speed. But if the orbits of ship and planet *cross*, the ship not only has to change direction but it also has to eliminate a greater difference in velocities than in the case of touching orbits where the difference to be eliminated is not very large as cosmic velocities go. Naturally a much larger amount of fuel would have to be expended in the case of crossing orbits and, since this fuel had to be lifted from earth first, it does mean *much* more fuel—a much larger mass-ratio—at the beginning of the trip. It is easy to see why touching orbits are more economical than crossing orbits.

One cannot ask at this point whether such a thing could be done or not. The possibility or impossibility, the improbability or probability, if you prefer, depends mainly on the figures which result from definite calculations. There is no way of passing judgment until we know the figures for the velocities (or rather their changes) and the masses involved.

We can now proceed to some figures from which that answer may be derived. I'm going to follow the exposition of the problem as it was given in 1928 by Dr. Walter Hohmann in my book *Die Möglichkeit der Weltraumfahrt*. I am not going to repeat Dr. Hohmann's calculations, but only state the problems and give his results.

All the Hohmann orbits, as they have come to be called, are, as is natural, Keplerian Ellipses which lie in the plane of the ecliptic (the earth's orbit), and which follow the general rotation of the solar system and touch or cross at least two planetary orbits.

I have inserted the phrase "follow the general rotation of the solar system" advisedly. Naturally one can imagine and calculate a Keplerian Ellipse pointing in the opposite direction, but this



38. "Possible" and "Impossible" Spaceship Orbits.

would be a non-economical orbit *par excellence*. It would mean the acquisition of more than the orbital velocity of the earth *against* the orbital velocity of the earth (the ship, being a part of the earth before the take-off, naturally has earth's orbital velocity at the outset), and it would again mean reducing all this velocity to zero and acquiring a high velocity in the opposite direction to catch up with the orbital velocity of the target planet, all this leading up to a landing against that planet's gravitation. This is something that clearly cannot be done, and orbits which do not follow the general rotation of the solar system are therefore ruled out as "impossible orbits." (Fig. 38.)

As regards the "possible" orbits, Dr. Hohmann simplified the calculations somewhat by making two assumptions about the orbits

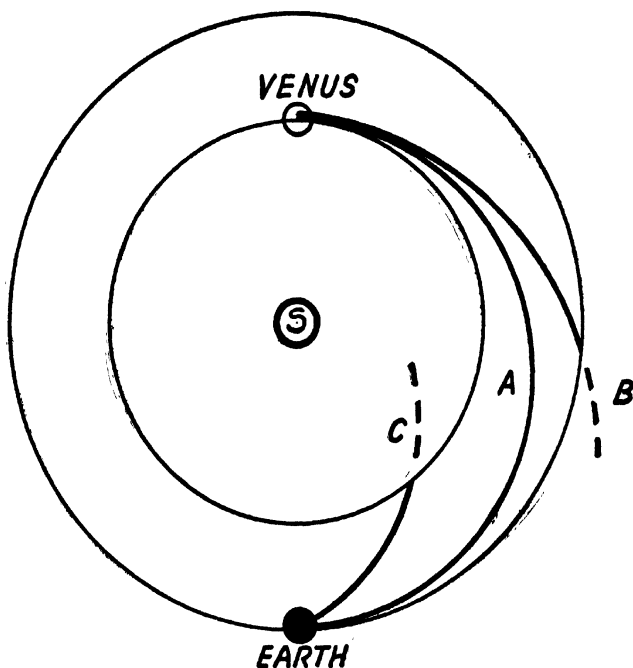
of the planets. We know that they are elliptical but to such a small extent that they look like circles on a small drawing. And we also know that they are tilted against the plane of the earth's orbit to a very slight degree. Dr. Hohmann made the two assumptions that the orbits of the inner planets lie precisely in the same plane and that they are circular. The latter assumption has the purpose of getting rid of the complication that would otherwise arise from the fact that the planets travel somewhat faster at perihelion than at aphelion. He assumed that the *average* orbital velocity of a planet held true for every point of the orbit. Expressed in slightly more technical language he assumed that the *radius vector* does not only sweep over equal areas during equal time intervals, but that it also describes equal angles. The difference between this simplified picture and actual conditions is such that it would spell doom for a spaceship whose navigator lightens his duties in a similar manner. But it is not large enough to change the figures to an important extent and at present we only want some general figures which can serve as a basis for conclusions about the probability of the whole venture.

Dr. Hohmann's first example is a trip to Venus and he started out by drawing five possible orbits called A, B, C, D, and E. Orbit A touches the orbits of both Venus and the earth, orbit B crosses the orbit of earth but touches the orbit of Venus, while orbit C touches the orbit of earth but crosses that of Venus. Orbit D is similar to C, only less abrupt, while orbit E is of the same type as orbit B. The spaceship was supposed to arrive at Venus and adjust its velocity, but not to land. Its final weight, at that moment, was assumed to be 6 tons, including three passengers. The allowance for the passengers during the trip had been 10 kilograms or 22 pounds per man per day which is, at any event, ample. (Fig. 39.)

The results are condensed in the following table which should be studied carefully:

ORBIT USED	DURATION OF TRIP	ORIGINAL MASS OF SHIP IN TONS *			
		(1)	(2)	(3)	(4)
A	146 days	49	34	27	18
B	75 days	530	200	104	31
C	69 days	5,900	1,060	417	60
D	109 days	141	70	48	22
E	102 days	172	83	55	24

* The term "ton" always means 1000 kilograms or 2200 pounds.



39. Hohmann Orbits.

Now we can see in figures how economical the A orbit turns out to be, even though it takes twice as long to complete as the B or C orbit. That there are four columns of figures for the original weight of the ship is explained by the assumption of four different exhaust velocities. The figures in column (1) refer to an exhaust velocity of 3000 meters per second, the best that can be expected from gasoline and oxygen. The figures in column (2) refer to an exhaust velocity of 4000 meters per second which may be expected from hydrogen and oxygen. Those in column (3) are for an exhaust velocity of 5000 meters per second, the best that can be expected from hydrogen and ozone. The figures in the last column (4) are based upon an exhaust velocity of 10,000 meters per second; we have no idea at present how that could be done.

This first table settles one point: only A orbits can be considered

at all. Any orbit that crosses a planetary orbit and involves a change of direction has to be ruled out almost as strictly as an orbit that does not follow the general rotation of the solar system.

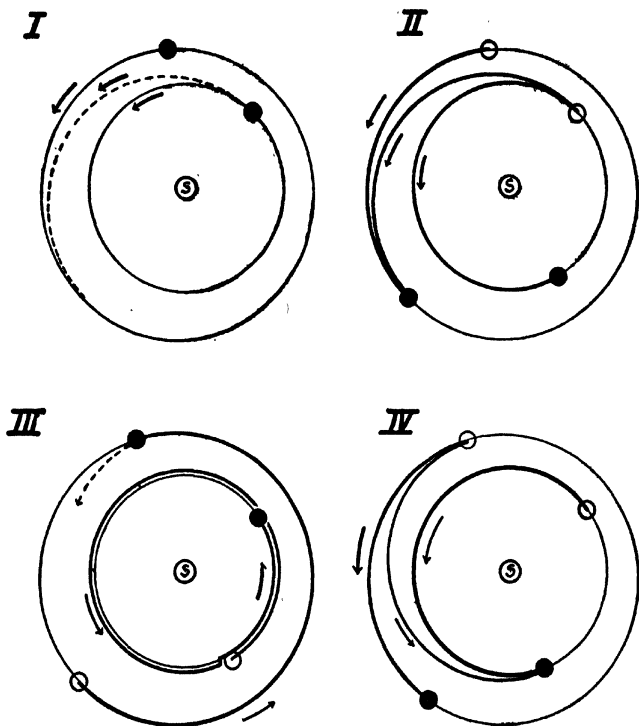
But those figures must not be misunderstood. They do not mean that a 6-ton ship, burning hydrogen and ozone (and having an exhaust velocity of 5000 meters per second) would need 21 tons of fuel to get to Venus in 146 days. Or that, burning gasoline and oxygen, it would need 43 tons of fuel for the trip. If that were the whole of the story, we might seriously think about the construction of a spaceship some time next week.

These figures merely express the tribute that has to be paid to the sun for moving from the orbit of earth to the orbit of Venus and regulating the velocities so that they agree with those of the planets at both ends. So far the two planets have been treated as if they had no gravitational power of their own. The figures in the table do *not* include the departure from earth. Nor has anything been said about the return. So far the only thing that can be kept in mind as definite is the duration of the trip: 146 days. Similarly the duration of the trip to Mars along an A orbit would require 258 days.

Before we try to establish the true mass-ratios required—the mass-ratios which include departure from the earth, landing, and similar problems—we have to find out the true duration of the trip which means the duration of a *round trip*. It is not simply twice 146 days in the case of Venus or twice 258 days in the case of Mars. The planets move.

Supposing we have completed an A orbit to Mars and have, for some reason, decided not to land but to return at once. The thing to do, it would seem, would be not to adjust the ship's velocity to the velocity of Mars at all but simply to stay in the same orbit. Without requiring the expenditure of any fuel the orbit would carry us back without fail, back to the orbit of the earth. But the earth itself would be elsewhere.

When we departed from the earth, the slower Mars was far ahead. The time of departure was calculated in such a manner that the ship would catch up with the planet. But during the 258 days the relatively fast earth raced ahead. At the end of the trip the earth would be far from the point touched by the return orbit. There is no other way out but to linger on or near Mars until Mars is ahead of the earth which means, of course, until the earth is behind by having completed more than one full revolution around



40. A Trip to Mars and Back.

I.—Position of planets (black circles) at beginning of trip (broken line shows orbit traveled by spaceship); II.—Position at moment of arrival on Mars (previous position shown by white circles); III.—Position at date of departure from Mars (Mars has completed the whole journey from the white to black circle and the earth has traveled around its whole orbit almost one and one quarter times); IV.—Position at date of spaceship's arrival on earth.

the sun. This waiting period is unfortunately rather long; it amounts to 455 days. Thus the round trip to Mars requires $258 + 455 + 258 = 971$ days or about two years and eight months. (Fig. 40.)

On a round trip to Venus conditions are reversed since Venus is faster than the earth, but the net result is again a waiting period on or near Venus. It is even a little longer: 470 days. The duration of the whole round trip is, consequently, $146 + 470 + 146 = 762$ days, or two years and a month. It is seven months shorter than

the round trip to Mars, simply because of the shorter duration of the trips themselves, even though the waiting period is two weeks longer.

Now for the mass-ratios required. The table of mass-ratios for the departure from earth looks like this:

EARTH	EXHAUST VELOCITY			
	3000 m/sec.	4000 m/sec.	5000 m/sec.	10,000 m/sec.
	95	30	15	4

Air resistance and mild acceleration for the sake of the pilot are included in this table. These figures are not tons, they are ratios. If you would like to find out for yourself what initial masses you have to count on for going to Venus, you can make a choice of exhaust velocity, pick the proper figure for the Venus trip from the table on page 217, and multiply it with the figure for the same exhaust velocity in the table just given. This is not the proper way of making the calculation and it is impossibly bad from the point of view of a mathematician, but it will give you approximate results.

Things begin to look very dark now. The mass-ratios become enormous. And with all that expenditure you just manage to get off the earth, drift to Venus, adjust your velocity there, and make a landing of the type described for the returning moonship.

If you had picked Mars you would need additional fuel to effect a landing against the gravity of Mars, since the Martian atmosphere cannot be counted upon to serve in the same manner as the atmospheres of the earth and of Venus. (The proper figures will follow in a moment.)

The procedure of the trip, as outlined by Hohmann, would be to ascend from the earth vertically in an arbitrary direction, until the ship is 500,000 miles from the surface. At this distance the gravitational field of the earth can be neglected. The ship is now independent of the earth, but still has the same orbital velocity as the earth. Now change the orbital velocity of the ship, a change of some 2 miles per second. The ship is now on its way, drifting inward in the solar system along an A orbit. During the initial ascent, which takes a few days, the rocket motors work for about eight minutes; in order to change the orbital velocity they work for another two minutes. From then on they are silent until the orbit of Venus and Venus itself are reached. But the ship during

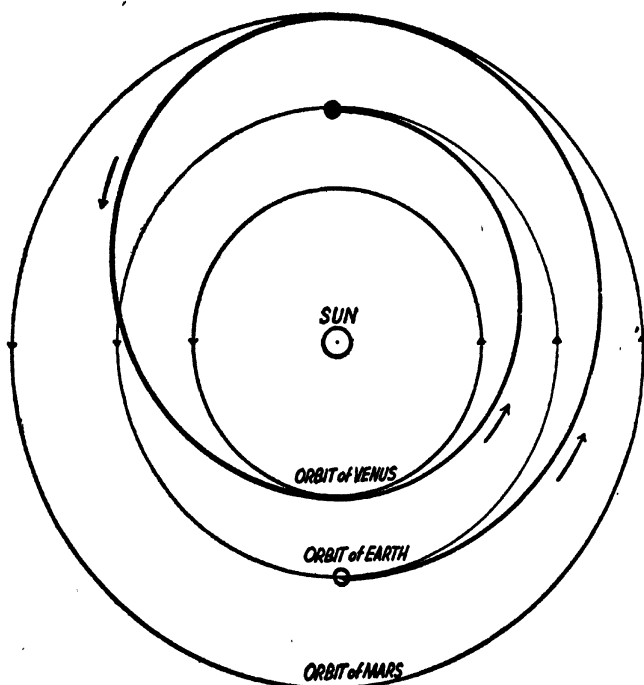
the inward drift, which is really a fall toward the sun, has gathered speed; it is now somewhat faster than Venus. That difference has to be adjusted; Venus and the ship are then really in the same orbit, moving with the same velocity. This is, of course, an unstable condition. The gravity of the planet will draw the ship down ("down" as seen from the planet) and the landing maneuver will have to begin. The landing maneuver is again designed to kill speed, but this time it is the speed resulting from the attraction of the planet. All this holds true for a trip to Mars too, except that the landing would require the expenditure of fuel to kill the falling speed of the ship.

Here are the figures I promised, all neatly condensed into one table. They are valid for a 6-ton ship with three passengers, each of whom has a food-water-oxygen allowance of 22 pounds per day.

EXHAUST VELOCITY AVAILABLE (meters per second)	INITIAL MASS OF SHIP REQUIRED (in tons)			
	TRIP		RETURN (independent)	
	to Venus	to Mars	from Venus	from Mars
3,000	4,680	29,500	2,510	382
4,000	1,020	4,180	690	182
5,000	410	1,260	276	110
10,000	73	135	64	41

It can be seen that it is, comparatively speaking, easier to go to Venus, but it is easier to return from Mars. The figures really are not bearable except for those which refer to the 10,000-meter-per-second exhaust velocity which we don't know how to achieve at the present moment. And there is another unpleasantness in that table; the figures for the return trip are for an *independent return*, which means that the fuel supply for the return trip is not carried along but is taken on (or manufactured) on the other planet. The idea of manufacturing the fuel for the return trip is not quite as farfetched as it may seem; the raw materials or rather the raw material for all oxygen-hydrogen or ozone-hydrogen combinations is simply water. And the energy needed for the manufacturing might well be solar energy—we are just now beginning to learn how it may be used. And the waiting period does provide time.

The first trip, of course, would not be one with a landing on the planet, especially since it is likely that all the information needed for future plans can be gathered by way of prolonged close observation of the planet. This then would be a round trip during which the waiting period is spent circling the planet.



41. The So-Called Hohmann Round Trip.

The mass-ratios for such a venture, again for a 6-ton ship with the usual assumptions, are given in the following table:

EXHAUST VELOCITY AVAILABLE (meters per second)	INITIAL MASS OF SHIP (in tons)		
	EARTH-MARS- EARTH, with circling of planet	EARTH-VENUS- EARTH, with circling of planet	SPECIAL ROUND TRIP
3,000	65,500	40,000	46,300
4,000	9,400	6,330	6,700
5,000	3,100	2,160	2,160
10,000	356	284	244

Again only the figures in the bottom line look bearable, but it is always amazing to see how just a slight increase in exhaust speed slashes away at the mass-ratio requirements.

The figures in the last column, labeled "special round trip," need some explanation and a diagram (Fig. 41). It is assumed here that

the ship goes to Mars, but that it does not land. But neither does it spend the whole waiting period circling Mars. After several weeks, say, the pilot decreases the orbital velocity and begins to drift inward along an A orbit which leads directly from the orbit of Mars to that of Venus; earth's orbit is naturally crossed on the way, but the earth is nowhere in sight. Venus, however, is at the meeting place and is circled for a while. The orbital speed of the ship is then increased again so that it is flung into an A orbit to the earth, reaching earth one and a half years after the original departure and having accomplished a survey of both planets in a shorter time and with slightly less fuel expenditure than that required for a no-landing trip to Venus alone.

This survey of Hohmann's excellent early work—it may be well to remember that Hohmann worked out all these things when the most powerful rockets on record were still the old Congreve war rockets—has shown that the problem of interplanetary travel lends itself to a cool mathematical investigation. It has also shown that the concept of trips to the two neighboring planets completely lacks the dare-devil hit-or-miss spirit with which it is imbued in stories of that kind. Actually that concept is a cold-blooded piece of planning, based on well-established natural laws. Another result which has emerged, so to speak in passing, is that the question of time is not of the order of that famous schoolbook example of the cannon ball which, "if it could be fired at the sun would need two centuries to get there." The trips are of the order of the average duration of extended expeditions on earth.

All this is very gratifying indeed, and it is not the fault of the investigator that the mass-ratios turned out to be on the impossible side most of the time. In fact all the mass-ratios dealing with things bigger than the unmanned moon rocket and the manned rocket around the moon are obviously beyond the possibility of construction. For interplanetary trips—as distinct from attempts at reaching the moon—only those mass-ratios where an exhaust velocity of 10,000 meters per second was assumed looked reasonable in some cases.

The need for such a high exhaust velocity fuel was also confirmed by Count Guido von Pirquet. Count von Pirquet is (or was—I don't know what has happened to him since the Nazis took Austria) a member of an old noble family in Austria, a family which is also

noted in the annals of science. His brother was one of Vienna's foremost and most famous pediatricians. When Pirquet became interested in space travel problems he put all his Viennese enthusiasm to the task. But he made his living as a practical engineer, and consequently he approached the problem from an angle which had virtually escaped the attention of the others. Other authors had bemoaned the high initial mass of a spaceship. Pirquet perceived another engineering impossibility connected with that high mass.

In the first place he pointed out that a manned ship cannot be operated as simply as a straight rocket. We have seen that, since the thrust always remains about the same but the mass of the rocket diminishes because of fuel consumption, the acceleration goes up. In fact for meteorological rockets and space rockets we accepted that fact with pleasure, we found it advantageous that the acceleration goes up at higher altitudes. But for a spaceship, with a man or men aboard, such steadily increasing acceleration won't do. An acceleration which starts out with, say, $3g$, and then goes up to $10g$ is fine for the performance of the ship, but the men inside won't be able to stand it.

Consequently in a manned spaceship the thrust of the motors has to be adjusted to the diminishing weight of the ship, so that the acceleration stays at $3g$ or $4g$ or whatever has been found to be the highest that the men can stand without discomfort. Since the exhaust velocity for a given fuel and motor does not change—and since it would be the peak of foolishness to cut the exhaust velocity, say, by means of deliberately faulty mixtures—the adjustment can be accomplished only by diminishing the rate of fuel feed.

But it was not the aspect of adjusting the power of the motors gradually which worried von Pirquet most, even though that may be somewhat difficult to accomplish in actual practice. What worried him was, on the contrary, the problem of fuel supply for the first few seconds of ascent. At take-off the ship is enormously heavy. Consequently the amount of fuel to be burned to lift it off the ground while it is so heavy is simply fantastic.

Pirquet took an exhaust velocity of 4000 meters per second, the figure used by Oberth for the calculation of the moonship, and then calculated the weight of a Marsship on that basis. After that he tried to determine the amount of fuel required for the first second of take-off, to lift the Marsship off the ground.

One hundred and five tons for the first second!

It is no consolation to know that it will be much less only fifteen seconds later. It has to be that much for the first second, and almost as much for the four or five following seconds. And, needless to say, the motors must be able to handle that amount. Only for a few seconds, to be sure, but they must handle it for these few seconds.

Pirquet calculated the size of a rocket motor which could handle over a hundred tons of fuel per second. The area of the throat, the narrowest point of the nozzle, would have to be 150 square meters, or about 1615 square feet. And the area of the mouth of the exhaust nozzle would have to be 1500 square meters, or 16,146 square feet. No matter how many motors and exhaust nozzles you use to split up these figures, they remain fantastic even on paper. And nobody can build anything like that.

This shows that it is not only impossible to build the necessary mass-ratios for interplanetary ships if they are supposed to make direct trips, it also shows that the ship could not lift off for direct take-off, even if it could be built. With an exhaust velocity of 4000 or even 5000 meters it simply cannot be done at all. But if there were a 10,000 meter per second fuel, you could divide the two figures just given by about twenty . . . and then they begin to look more reasonable.

Hohmann, too, used that figure for purposes of comparison, mainly in order to show just what such a high exhaust velocity could do. He might vaguely have thought of monatomic hydrogen when he selected the figure 10,000 since that is about what monatomic hydrogen would be expected to yield if it could be manufactured and used.

But now, only twenty years later, we can begin to think in terms of atomic energy. With the aid of disintegrating atoms of Uranium-235 we can hope to obtain not only 10,000 meters per second, but even 20,000 meters per second. And if somebody expects 50,000 meters per second there is little reason to contradict him, except for saying that that might take a little while longer.

In order to show what such high exhaust velocities would do to the mass-ratios we have to go back to Oberth's moonship (page 257) for an example and a method. It may have been noticed that Prof. Oberth and Dr. Hohmann used different approaches in arriving at their mass-ratios. Oberth's method consisted in ascertaining the magnitudes of the changes in velocity required for the

various maneuvers. These changes, expressed in meters per second, he called "ideal velocities." They are then added up, so that you get a figure for the whole trip. The *sum* of all the changes in velocity that have to be accomplished by rocket power is the "ideal velocity" for the planned trip, like that figure of 19,310 meters per second for a trip to the moon with landing on the moon and parachute landing on earth on return.

The mass-ratio for the whole trip is then found very simple by calculating the mass-ratio for the "ideal velocity" with a given exhaust velocity.

Dr. Hohmann established the mass-ratio for each maneuver separately; the total mass-ratio requirement for a planned trip is the *product* of multiplication of the various mass-ratios with each other. Each of these two methods has advantages and disadvantages of its own; Hohmann's method is more graphic and also more accurate, Oberth's is simpler in operation and a handier tool. I am going to follow Oberth's method from now on, partly because of its handiness, partly because it also has to do with a fuel-saving method of leaving the earth.

In rocket literature that fuel-saving method goes under the clumsy but appropriate name of "the problem of the condensation of power application." Hohmann's hypothetical pilot, you remember, first left earth in an arbitrary direction to become virtually freed of the gravitational attraction of the home planet. Then he changed the orbital velocity of the ship, which was still the same as earth's, with respect to the sun. After that he went into the next maneuver, etc.

It is obvious, even without a detailed study, that a combination of ascent from the earth and change of orbital velocity, accomplished, one might say, "in one sweep," would save a lot of fuel. Oberth, upon investigation, found that a straight vertical ascent is rather wasteful, especially if the acceleration has to be reined in for the sake of a pilot.

To obtain escape velocity in a vertical ascent you have to have an "ideal velocity" which is somewhat higher. This may sound paradoxical, but the explanation is simple: escape velocity is what you get, "ideal velocity" is the price you have to pay. That price varies with the boldness of your trading, in other words with the acceleration you dare to use. For an acceleration of just 1g effective the ideal velocity is 14,080 meters per second. For an acceleration of

2½g effective it is 13,500 meters per second. And for an acceleration of 3g effective it is only 12,700 meters per second.

If you could take off horizontally you could use a higher acceleration since the acceleration of the ship and the acceleration resulting from the earth's attraction no longer have the same direction. The higher acceleration would result in increased efficiency. Taking off horizontally you could save some more by taking off due East, in the direction of the earth's rotation. The speed resulting from the earth's rotation (and it is considerable, especially near the equator) would thus be utilized by the ship, a kind of final gift of Mother Earth to its departing child. Naturally a really horizontal take-off is impossible because it would find too much air resistance. The initial portion of the ascent, say to twenty or thirty miles, should be vertical, then more tilted and change into horizontal above 60 miles. Once outside the atmosphere, the ship would go on increasing its velocity so that the necessary change of orbital velocity is a part of the same maneuver. In some cases it might be necessary to go half around the earth outside the atmosphere, but that would not involve any losses.

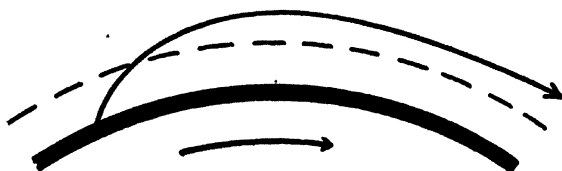
The compromise between the most efficient ascent, horizontally due East, and avoidance of air resistance, etc., was called "curve of synergy" by Oberth (Fig. 42), and he found that the ideal velocity for a synergic ascent was between 11,500 and 12,000 meters per second, a saving of between 700 and 2100 meters per second.

Now, knowing about the synergic ascent, we can talk about mass-ratios again and we can at once insert the figures for exhaust velocities of 10,000 and 20,000 meters per second, presumably obtainable from atomic fuels.

We'll begin with the simple ascent made in order to obtain escape velocity. In the following table "Case A" refers to a vertical ascent with an acceleration of 1g effective, "Case B" to a vertical ascent with 3g effective, and "Case C" to the synergic ascent.

	MASS-RATIOS REQUIRED WITH EXHAUST VELOCITY (meters per second)		
	4000	10,000	20,000
Case A	33	4.06	2.0
Case B	25.8	3.60	1.95
Case C	20.1	3.32	1.82

The synergic ascent, with a 20,000 meter per second atomic fuel, requires a mass-ratio of less than 2:1 for attaining escape



42. Oberth's "Synergy Curve."

velocity, something that could be built at once if such a fuel were available.

The moon trip with landing which required a mass-ratio of 134:1, for a fuel with an exhaust velocity of 4000 meters per second, would require only a mass-ratio of 7.4:1 for a 10,000 meter per second fuel and a mass-ratio of 2.72:1 for a 20,000 meter per second fuel. Again the latter could be built at once if such a fuel were available.

To reach Venus, with parachute landing there and independent return, an "ideal velocity" of 13,000 meters per second would be needed; for going to Venus, circling the planet, and returning to earth with parachute landing on earth an "ideal velocity" of 20,000 meters per second would do. To reach Mercury with circling, return without landing, and parachute landing on earth the "ideal velocity" required would be twice as high, namely 40,000 meters per second, because of Mercury's proximity to the sun.

Written in the form of a table, these three cases would look like this:

TRIP	MASS-RATIOS REQUIRED WITH EXHAUST VELOCITY (meters per second)		
	4000	10,000	20,000
One-way to Venus (with parachute landing there)	25.8	3.8	1.95
Round trip to Venus (with circling of planet, return to earth, and parachute landing)	148	7.4	2.72
Round trip to Mercury (with circling of planet, return to earth, and parachute landing)	22,070	54.5	7.40

In the Mars trip the synergic ascent, etc., would constitute an enormous saving as compared to Hohmann's method. The least saving would amount to 2850 meters per second, the highest pos-

sible saving to 4800 meters per second. Using the highest expenditure of Oberth's method the mass-ratio for the trip would be almost precisely 27 for an exhaust velocity of 4000 meters per second; about 4.2 for a 10,000 meter per second fuel; and just about 2 for a 20,000 meter per second fuel. These figures, however, have to be regarded with some slight suspicion because Oberth assumed that the atmosphere of Mars is dense enough to permit a parachute landing. This is doubtful, and it will be safer by far to make the assumption that the atmosphere of Mars does not count at all. In that case the "ideal velocity" required would jump up to 20,000 meters per second and the mass-ratios for this figure happen to be the same as those quoted in the table above for the round trip to Venus without landing there, but with return to earth and parachute landing on earth.

That, however, would just get the ship safely to the surface of Mars; you would still have to worry about independent return although Mars certainly does have water which might take care of the greater part of the fuel problem.

If the idea is to go to Mars and to circle the planet without landing (or with landing on either one of its two tiny moons) and subsequent return to earth with parachute landing on earth, the "ideal velocity" would have to be 25,000 meters per second, resulting in a mass-ratio of 12.2:1 for a 10,000 meter per second fuel and a mass-ratio of 3.5:1 for a 20,000 meter per second fuel.

There is no way of telling just how an atomic spaceship drive would look and how it would work. The following is not even meant as an engineering guess, but merely as an aid to visualize the possible shape or method of operation.

What we now know about atomic energy is this: the element uranium, a heavy silvery-white metal which has about the same specific gravity as gold, exists in three so-called isotopes, named U-234, U-235, and U-238. Of these U-234 is so rare that it may be disregarded. The most common form is U-238, but one out of every 140 atoms is of the variety U-235. The numbers refer to the relative weights of the atoms. Both varieties have 92 negatively charged electrons swirling around the nucleus and because of that they are chemically alike. Both are also alike in having 92 positively charged protons in the nucleus, but the nucleus of the variety 238, the common variety, also contains 146 neutrons, subatomic particles of about the same weight as the protons, but without any elec-

tric charge. The rarer U-235 has 92 protons and 143 neutrons ($92 + 143 = 235$) and it is this rare variety which will collapse into smaller atoms, mainly barium and krypton, when an additional neutron wanders into its nucleus. Because of the tremendous release of energy, this breakdown appears to be an ultra-violent explosion, with most of the energy released as plain heat. In collapsing, the U-235 atom also emits more neutrons which, however, do not cause additional atom explosions since they are too fast to react. In order to react they have to be slowed down, which can be done only by bouncing them around among atoms that are not much heavier than the neutrons are themselves. In the early experiments the physicists employed hydrogen atoms, made available in their compounds water or paraffin. Later it was found that carbon atoms—provided in the form of graphite—could also be used for slowing down neutrons.

During these experiments, which led to the atomic bomb, it was found that the heavier U-238, which does not react explosively directly, will absorb a good number of the new (and slowed down) neutrons and thereby change into still another form of uranium, U-239. But U-239 is not stable. One of its neutrons changes into a proton, thus bringing the number of positive charges in the nucleus up to 93 and thereby producing a new element, called Neptunium, which also is not stable. Another neutron changes sides, becomes positive, and element number 94, called Plutonium, is the result. Plutonium is reasonably stable, which means that it will last long enough to permit military use. In the end, however, the Plutonium nucleus would shoot out an alpha particle (which consists of two protons and two neutrons) and would thereby change the atom of 94 positive charges and mass 239 into an atom of 92 positive charges and mass 235—the famous U-235.

Now the energy that can be obtained from U-235 is that of gasoline, multiplied by three million! There is, obviously, enough energy available for spaceship needs. But equally obviously U-235 could not be used by itself; the exhaust velocity would be tremendous, but the exhaust mass would be ridiculously small. Hence the energy from the U-235 would probably best be utilized by way of making it eject some other substance: water. Water is the best bet. It is comparatively heavy and dense, which keeps the tanks small, it is abundant on Mars and Venus, at least abundant for this particular purpose. It may even be found on the moon in sufficient

quantities. It also happens to have the proper qualities to keep the atomic reaction going.

Now some uranium salts, the salts of U-235 for this purpose, are soluble in water—a watery solution of U-235 compounds may be the spaceship fuel needed for the fantastic exhaust velocities which create the convenient small mass-ratios. Or one may imagine the U-235 metal carried in the form of a thin wire which is fed into the combustion chamber at the proper rate, with enough water pumped in simultaneously to produce a sufficient exhaust mass. There may be, there most likely are, still other ways in which the energy of exploding U-235 atoms can be utilized.

The important point is that we now know of a fuel which, theoretically at least, can produce ultra-fast exhaust velocities. We will see in the concluding chapter that space travel would be realizable even without such fuels. But it would be nice to have them.

Chapter 12:

TERMINAL IN SPACE

Space travel is not a problem of "quantities of work," but a problem of "quantities of movement."—Dr. Franz von Hoefft (1928); paraphrased by Robert Esnault-Pelterie (1930).

WITHOUT atomic energy not very many of the goals of rocket research are within direct reach. We can, of course, build high-altitude rockets of all kinds and sizes. We can go out into space, with observers aboard, for several earth diameters. We can send unmanned rockets to the moon and we might toy with the idea of a manned trip around the moon.

Landing on the moon is already beyond the borderline of what chemical fuels can do. And to reach the neighboring planets directly will certainly require the use of atomic energy. But even when atomic energy was still thought to be centuries in the future there existed a theoretical method of landing on the moon and of going to Mars and to Venus with chemical fuels. That theoretical method was a refueling terminal in space, a cosmic stepping stone for spaceships which were too weak to reach another planet directly.

Such a station had been one of the main features of Kurd Lasswitz' famous novel. Hermann Ganswindt had harbored some rather vague ideas of that kind. Hermann Oberth, in his first publication of 1923, had suggested such a station for experimental purposes, with the refueling angle as an afterthought. It remained for Count von Pirquet to realize that the station in space, regarded by many as an interesting by-product, was actually the key to interplanetary travel. He arrived at the conclusion that interplanetary travel directly from earth was impossible (with chemical fuels) but that the establishment of the station in space was possible, even though difficult. But once the station was established, the problem of interplanetary travel not only became a possibility, it actually turned out to be easier than the establishment of the station itself.

He proved his assertion—we'll go into that later—and called it the "cosmonautic paradox." And there can be no doubt that it was von Pirquet's work which prompted the experimenters of Peenemünde to put the establishment of the space station on their program as one of the major projects of Nazi Germany after the subjugation of the planet.

Newspaper accounts which were published when these plans were released placed most, if not all, the emphasis on the suggested use of a giant mirror, which they dubbed the "sun gun." The captured Nazi documents may have contained such a reference to the so-called solar mirror which will be discussed and explained shortly. But actually the solar mirror is only a side issue. The real value of the idea lies elsewhere. Nor would the invention of an atomic spaceship drive make such a station obsolete before anybody got around to establishing it.

Even spaceships with atomic drive may find the space station useful, but whether they do or not, the station will be built if humanity can avoid an atomic war. It has so many attractive and useful features that it is a valuable project in its own right; even more "valuable" since it shows promises of financial returns, financial returns of such an enormous order of magnitude that they will pay for all the preliminary and actual work within ten or fifteen years after its establishment, if not sooner.

The question "what holds it up" is proverbially the first question always asked when the station is under discussion. Only physicists fail to ask it, because the whole idea is based on a simple physical principle.

In most physics books you can find an illustration looking more or less like Fig. 43. It shows the earth with an imaginary mountain of colossal dimensions—its peak being out in empty space—with an imaginary gun on top of it. In connection with this picture it is stated that the horizontal range of that gun would vary with the muzzle velocity of the projectile, but that the gun could also fire around the earth—and presumably hit itself—if the muzzle velocity were large enough. The muzzle velocity required for this experiment, the book goes on to say, is 8000 meters or just about 5 miles per second. And this velocity is called the "circular velocity," because the projectile would continue to circle the earth indefinitely.

All these statements are correct, of course, but experience has



43. "Circular Velocity."

taught me that many people never quite stop wondering why the projectile does not "fall." The answer is that it does, but that it falls *around* the earth.

This strange statement may become clear if we look at it this way: for any kind of shot the projectile describes two motions at the same time. The first of the two is due to muzzle velocity. If the second motion, caused by gravitational attraction, did not interfere, the first motion would be horizontal in a straight line. If the projectile had no muzzle velocity, it would describe only the second motion—a straight fall to the ground. Together the two motions produce a curve—the projectile moves sidewise and falls downward simultaneously. The speed of fall does not vary from shot to shot, but the muzzle velocity can be changed. If the muzzle velocity is high, the curve will be shallow; if it is low, the curve will be steep.

If the muzzle velocity gets very high, the range is increased by another factor: the curvature of the earth. For low muzzle velocities (such as are actually in use) that factor does not show. The curvature of the earth, compared with the curvature of the projectile's trajectory, is so "shallow" that it can be taken for a straight

line. But if the trajectory's curvature is shallow too, the curvature of the earth's surface will become more apparent. And in the end one curve will be as shallow as the other; the projectile, while falling, will never reach the ground. The earth's surface, in a manner of speaking, curves downward as fast as gravity causes the projectile to approach it.

This takes place when the sidewise motion is about 5 miles per second. No gun could ever do it—nor would it be of any use to anybody if it could be done.

But a spaceship, taking off along a synergic curve, could get into such a circular orbit much more easily than it could get to the moon. Since the velocity required to establish an orbit around the earth (say at an altitude of 500 miles to be safely outside the atmosphere) is much less than that required to produce a circumnavigation of the moon, it is obvious that the mass-ratios required will be much smaller too.

While in that orbit, no fuel would need to be expended. As far as fuel requirements go, it does not matter whether the ship circles the earth once, twice, or fifty times; the requirements are always the same: zero. Expenditure of fuel is needed only when the pilot wants to return—then it is necessary to slow the velocity of the ship so that it finally touches the atmosphere and carries out the landing maneuver described previously.

This, obviously, will be done before anybody even sets out for the trip around the moon. Circling the earth in such a manner, ship and pilot will experience all the sensations of coasting in free space. There are many misconceptions about the healthfulness of this experience, a question which is yet to be discussed.

After Oberth had shown that Lasswitz' dream of a station in space was not just a dream, a captain Potočnik of the old Imperial Austrian army wrote a whole book on the space station, under the pen name of Wilhelm Noordung. (See *Bibliography*.) However, this book could hardly be called a "contribution," and there was no advance until Count von Pirquet published several articles in the monthly journal of the *VfR*, the most important of which can be found in *Die Rakete*, 1928, vol. II, pp. 134-40.

Making generous allowances, and counting on an exhaust velocity of only 4000 meters per second, von Pirquet arrived at a mass-ratio of 68:1, for a 2-ton ship with a take-off weight of 140 tons.

The maximum ejection required for such a ship would be 1.5 tons per second which can be handled by a rocket motor with a nozzle area of about 23 square feet at the narrowest point. It is still a big figure, but no longer impossible. This may be accomplished in time, in the form of a number of smaller motors with an aggregate exhaust of 1.5 tons for the first second. A ship of such a mass-ratio would have to be a two-step ship. Pirquet naturally preferred a one-step ship, which would be possible, if granted an exhaust velocity of roughly 4 miles per second. With an exhaust velocity of just slightly above 4 miles per second a one-step ship could bring 3 tons of materials and provisions to the station with an initial weight of 40 tons and a maximum fuel expenditure of 660 pounds per second. Pirquet wanted mainly to find out at what point two-step ships could be abandoned. The important discovery was that the circling spaceship can be established in its closed orbit with present-day fuels: oxygen and hydrogen with an exhaust velocity of 4000 meters per second.

The idea is, logically, to leave the ship in its orbit, to supply building materials—at the expense of a maximum of 68 tons of fuel for every ton of equipment and supplies that gets there—and to build a permanent station around the first ship.

For some psychological reason the idea of a station in space seems more farfetched than a trip to the moon. Actually it is simpler. Jules Verne, in his second novel, had the crew of his projectile encounter a second small moon of the earth, circling the earth 4700 miles above the surface in three hours and twenty minutes. This incident is based upon the now forgotten calculation of a French astronomer by the name of Petit. I mention it here only because the hypothesis of such a small moon will help to understand why the problem of the station in space is the easiest of all space travel problems after the plain space rocket. It is many times as difficult as the problem of the space rocket, but it is still easier than the moon trip. Naturally it would be easier to reach a close (and incidentally small) moon than it would be to reach the distant (and incidentally large) moon which the earth actually has.

Trips to the moon, around the moon, and even to the other planets are no longer difficult if they are made from that station. That the gravitational potential of the earth is somewhat smaller for the distance at which the station circles our planet—at an altitude of between 500 and 600 miles—is helpful, but it is not im-

portant. It is far more important that no air resistance has to be overcome. But the most valuable factor is the high velocity of the station itself, amounting, as it does, to roughly 5 miles per second. And since the station circles the earth within a few hours, you can have that velocity pointing "forward" or "backward" as compared with the movement of earth. The waiting period from "forward" to "backward" is on the order of about one hour.

All in all, the conditions for a spaceship take-off are pretty nearly ideal. A velocity of about 5 miles per second to start with, no air resistance, plenty of room for maneuvering (and mistakes). The ship itself does not need to acquire much more velocity on its own—about 1.5 to 2.5 miles per second additional would suffice, depending on the target planet.

"Of course it could be said here," wrote Pirquet, "that you don't 'really' gain anything by relying on the station in space and the following example could be constructed: 68 tons of take-off weight are required for the transportation of each ton from the surface to the station in space. Consequently, if a trip to Mars from the station is contemplated, with a ship of $3 \times 170 = 510$ tons, the primary requirement is an expenditure of $500 \times 68 = 34,000$ tons which, of course, are transported piecemeal, most of it being used up for the transportation. But if you depart directly from earth, intending to return with a 3-ton ship, only $4800 \times 3 = 14,400$ tons are required, or only about 10,000 tons if you have a ship of 2 tons final weight. The latter is, of course, less expensive; the question is whether it can be done at all." The answer was that it couldn't.

You will have noticed that Pirquet arrived at a take-off weight of 170 tons (from the station) for a 3-ton Mars ship, a mass-ratio of about 57 to 1. With that mass-ratio, especially since the acceleration can be kept lower in free space, there is no need for excessively large motors. It might indeed be possible to reduce the mass-ratio some more by placing the curve of departure in such a manner that the ship at first approaches earth to a certain extent, falling in the general direction of the planet and thus gaining velocity. That gain does not count directly; naturally it is eaten up again by earth's gravity when the ship recedes after passing the point closest to it. Even in empty space you don't get something for nothing. But you do gain a little in such a maneuver: the motors work more efficiently when burning at a higher velocity. For those who, at this instant, are apt to bring forth the law of the conserva-

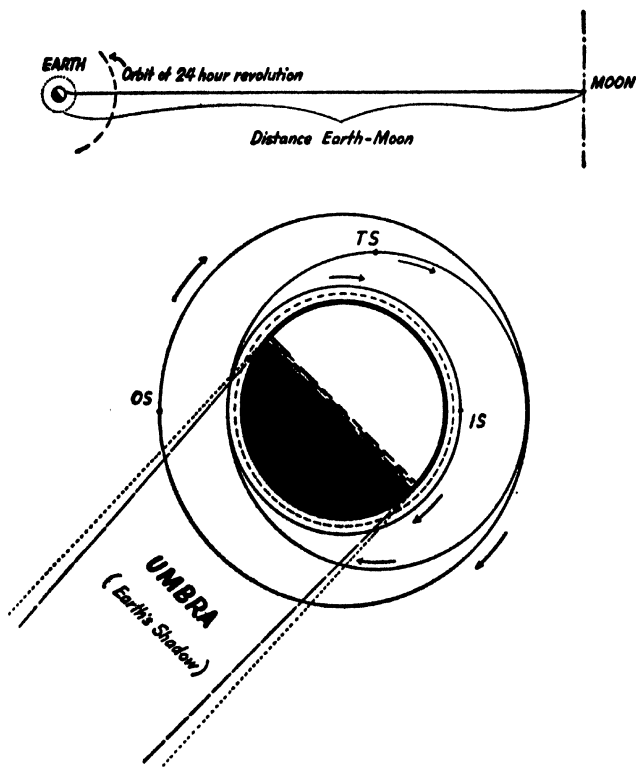
tion of energy, I hasten to remark that even that gain does not come out of "nothing"; it is some of the energy expended by lifting fuel to the station which you get back in this manner. I also have to add that the fuel expenditure per second for take-offs from the station is on the order of about 400 pounds.

All of which justified Count von Pirquet's statement that space travel with present-day fuels may be regarded as impossible, but that present-day fuels permit the realization of the station in space and that the station in space, in turn, facilitates space travel to an almost incredible extent.

Oberth and many others agreed with Pirquet, only Max Valier never fully subscribed to the theory of the station in space "since the moon is a natural station of this kind." This statement is about as valuable a contribution to the problem as Opel's rocket cars. The moon is much farther away and, as has been shown, much more expensive to reach. In addition to that, it has a gravitational field which needs an escape velocity of $1\frac{1}{2}$ miles or about 2.4 kilometers per second to overcome. And the gain in speed is anything but impressive; the orbital motion of the moon is not even two-thirds of a mile per second. The only real gain, which may outweigh all these disadvantages, would be manufacture of the fuel on the spot, provided that the raw materials could be found in sufficient quantities.

Professor Oberth wanted to place the station some 600 miles above sea level so that it would circle earth once in about four hours. The late Captain Potočnik, who has already been mentioned, was in favor of a station 35,900 kilometers or about 22,300 miles above sea level. At that altitude—or distance—the station would need precisely twenty-four hours to circle earth once which would mean, of course, that it would remain stationary over the same point. Potočnik even drew very elaborate plans showing how the station should look and how it should be designed. They were such that, immediately after the publication of his book, I wrote to Pirquet that "Noordung's plans are of great historical interest even now."

Pirquet, in turn, developed a kind of design of his own. It was not a design for the station itself—that can wait until we know more—but an "orbital design." Such a station, as we'll see soon, would have to serve for several purposes and for some of these purposes it would be desirable to have it as close to earth as pos-



44. The Three-Unit Station.

The Inner Station (IS) circles the planet just above the upper limits of the atmosphere (indicated by broken line). On top the distance earth-moon is drawn to scale. The dotted line around the earth is the orbit of the Outer Station and the broken line indicates the orbit of a station which would circle the earth once in twenty-four hours.

sible. For others a slightly larger distance would be preferable. The result is that more than one station, or a station consisting of more than one unit, seems indicated. Consequently Pirquet developed his "three-unit station," shown diagrammatically in Fig. 44.

The "Inner Station" (IS) would be 760 kilometers (about 475 miles) above sea level. The "Outer Station" (OS) would be 5000 kilometers (about 3125 miles) above sea level. Both would revolve

around the earth in practically circular orbits. A third unit, called the "Transit Station" (TS), running on an elongated elliptic orbit, is to connect the two, and the TS would be in the nature of a small spaceship. The interplay of motions of the three units was expressed by Pirquet as follows:

	ALTITUDE ABOVE SEA LEVEL (kilometers)	TIME REQUIRED FOR ONE COMPLETE REVOLUTION AROUND THE EARTH (minutes)
IS	760	100
TS	760-5,000	150
OS	5,000	200

This, according to Pirquet, is the optimum arrangement possible to satisfy all requirements. The TS is not to touch the orbits of the other two but only to approach them at the closest by little less than a mile. The difference in velocity between TS and either OS or IS at the moment of closest approach will be around three quarters of a mile per second, which would have to be adjusted if an actual transfer of men or materials is to take place. The TS is, so to speak, on a permanent "A" orbit between the two others. The gravitational attraction of even very large and massive stations will not be enough to disturb their mutual orbits seriously. Minor corrections, involving the expenditure of a few pounds of fuel, may become necessary from time to time.

The station in space, as evolved in theory by Pirquet, is mainly a terminal in space. Pirquet wanted to create a suitable base for exploratory trips through the solar system, a base which, by virtue of its own movements, facilitates the movements of vessels, and a base which serves as a fuel depot since liquefied gases, if they are only shielded against the rays of the sun, will keep indefinitely out there.

But there are many other things the station in space can do, things which would make it valuable even if no spaceship ever took off from there.

Conditions on the station differ from those on earth in three important respects:

(A) The station moves in a vacuum which is better or, as it is usually called, "harder" than any vacuum we can produce on earth. And even if we could produce a vacuum as hard as that, it would

be small in size indeed, while the vacuum surrounding the station is, for any practical purpose, infinite in extent.

(B) Any desired extremes of temperature can be produced easily on the station. Any object which is shielded against the direct radiation of the sun by a mirroring surface—for example, by thin sheets of sodium metal—will lose its own heat by radiation and within a few hours it will cool off to a temperature close to absolute zero, probably closer to absolute zero by fractions of a degree than can be accomplished in the laboratory. On the other hand it will be easy to concentrate the sun's rays upon an object, heating it to temperatures far surpassing the temperature of an electric arc.

(C) The station is under no gravitational strain whatever, even though it is comparatively close to our massive home planet. This is a condition which can be duplicated on earth only in a very restricted space for only a very short time by dropping bodies into an evacuated tube. The absence of gravitational strain is the result of the condition of "permanent free fall" (around the earth) prevailing on the station. If a body can freely follow the pull of gravity it is, of course, under no gravitational strain, since the strain is the result of the prevention of free fall.

Because of these three fundamentally different conditions, the station lends itself to experiments which cannot be performed, or cannot be performed well, on earth.

Condition (A)—the large hard vacuum—would produce a perfect laboratory for electronics engineers, and I am fairly certain that any electronics engineer reading this can think of a program of experimentation sufficient to keep a dozen researchers busy for years on the spur of the moment. Condition (B)—the accessibility of the whole temperature range—will be of special interest to physicists of any description. It may be added here that Condition (A) also implies the presence of an infinite pressureless space which might be of interest on many occasions, while Condition (B) implies the presence of radiations about which we know very little because they have trouble penetrating our atmosphere which is remarkably opaque to any but visible radiations. As a footnote to space-travel plans, it can be said here that ultra-violet radiation from the sun, useful for converting oxygen into ozone, is present in large amounts.

But the most important novelty is Condition (C) because it is something which virtually does not exist on earth. Physicists and chemists will be greatly interested to learn how molecular arrange-

ments take place under the apparent absence of gravity. We may find that this makes no difference, or it may make a great deal. We simply don't know at all whether a chemical reaction would proceed in the familiar manner under that condition. Just because gravitational strain is ever present on the surface, we have no idea what role, if any, it plays in everyday chemistry.

Biologists would like to investigate tissue growth under that condition. It would be interesting to find out, for example, whether an amoeba would split into two or not when it reaches the size where that usually happens. An amoeba of a thousand times its normal bulk would be absolutely helpless at the surface of the earth, would not be able to function, and would probably die. But at the station it may be able to grow to such a size, and such an experiment may lead to investigations about the nature of "life" which would be more successful than those made on the ground.

The lack of gravitational strain not only permits absolutely new experiments of all kinds; it also permits new ways of constructing known types of equipment and instruments. An astronomical telescope, for example, is a very massive instrument because of the gravitational strain. The tube of the telescope has the optical purpose of keeping stray light out of the instrument, but it has also the mechanical purpose of holding the main lens (in a refracting telescope) in place. The main lens is heavy but it must be perfectly "in line"; consequently the tube has to be very massive. At the station, with everything apparently weightless, the tube has to perform its optical duties only. Once the lens has been moved to its proper place, it stays there without exerting any mechanical strain on anything, and it can, therefore, weigh a great deal less.

This means, of course, that optical instruments can be much larger than those on earth. (The design would follow somewhat different principles, too, since nobody expects to move a heavy 200-inch mirror out into space.) They can also become much more effective.

The trouble with astronomical observatories, as Dr. R. S. Richardson of Mt. Wilson Observatory put it some time ago, is that their location condemns them to operate with only about 30 per cent of their possible efficiency—they have all been built on earth.² The

² Following this lament, Dr. Richardson described how he would build an observatory on the moon, with unimpeded vision. The amusing and interesting article appeared in *Street & Smith's Astounding* (February 1940).

reason for their low efficiency is, of course, the atmosphere which prevents astronomers from using the magnifications which are optically at their disposal. A comparatively small telescope—of a special design much too flimsy to hold together on the earth even for minutes—when used from the station could solve many of the problems which are so dear to the layman.

It could see the "fine detail" supposed to make up the optical illusion of the *canali* on Mars; we would find out whether they are an optical illusion or not. It could investigate certain areas on the moon, for example, those mysterious moving darkish spots in the "crater" Eratosthenes, discovered and described by Pickering. Since there is no dispersion of light, it would be easy to block out the sun and to observe Mercury at almost any time. As a matter of fact, the station would serve well to decide which places might be of interest for a visit to be planned. So far *everything* looks interesting because we don't know enough; the improved knowledge of an astronomy operating from a station in space will do considerable sifting in that respect.

Of course the station would permit taking spectrograms of the earth which would be of immense value for comparison with the spectrograms of other planets. It would also solve an important problem in astrophysics about which few laymen may even have heard: whether the so-called "red-shift" of distant bodies might not be caused in part or in toto by a secondary action of our atmosphere.³

Naturally observers on the station would have an excellent view of the earth. The airplane has taught us how advantageous it is to see things from above—how many things that cannot be seen at all on the ground appear clearly, such as shadings of the color of vegetation caused by the presence of certain minerals or elements.

The view of earth from the station will offer similar advantages on a larger scale. A trained observer could greatly assist weather bureaus all over the earth. He could, as far as the warning service is concerned, replace the ships of the North Atlantic Iceberg Patrol. He could observe ship movements of any kind (the term "ship" includes, of course, large aircraft), keep track of the movements

³ I wonder whether astronomers would not prefer the more distant station which revolves around the earth once in twenty-four hours. It would enable them to combine all the advantages of the station with established points, times, and methods of reference.

of expeditions, locate wrecks, advice about storm patterns—in short, he could render a large number of services of definite financial value.

Nor would that be all. Other uses for the station have been suggested. One of the most recent and most interesting suggestions is that advanced by Arthur C. Clarke of the combined British Interplanetary Society. In an article published in the October 1945 issue of the (British) magazine *Wireless World* he advocated a system of three space stations, revolving around earth in the same orbit (and forming a triangle with the earth in its center) for world-wide radio and television coverage. Since the three stations would be linked to each other by radio beams, all three would have access to any event observed by any one of them. On paper, at least, the expense of such a triple station would be less than for a really world-wide radio and television coverage accomplished by chains of ground stations with television aircraft, as others have suggested.

Another interesting problem is the solar mirror, one of Prof. Oberth's earliest suggestions. Oberth stated that prefabricated wire nets, carried up by rockets, could be unfolded very simply by rotating them around their centers. After unfolding the nets thin sheets of sodium metal would be inserted into the spaces between the wires to form the mirror proper.

Oberth selected sodium mainly because of its light weight. Weight for weight sodium would produce three times as much mirror surface as aluminum. Since there is neither oxygen nor moisture in space, the light and silver-bright sodium would not undergo the violent chemical reactions which characterize it on earth. The space mirror would reflect additional sunlight, sunlight which would normally "miss" the earth. Simple plane solar mirrors, placed in 24-hour orbits, could furnish evening illumination for large cities—for a fee, of course, which would have to be large enough to pay for the expense of erecting the mirror and maintaining it.

But such plane mirrors were only a side issue. Oberth was more interested in a large mirror which could be curved in order to focus the sun's rays. Such a curved mirror, Oberth wrote, could influence local climate, create or prevent storms, melt icebergs, "or, in case of war, burn cities, explode ammunition plants and do damage to the enemy generally."

The latter statement was not too carefully considered from the

practical point of view since it would be very difficult to give just the right amount of curvature to a sufficiently large mirror. But Oberth thought that the solar mirror constituted the ultimate war weapon. Like many other physicists he did not believe, as he told me in 1930, that atomic energy could ever be released, at least on any but a microscopic scale.

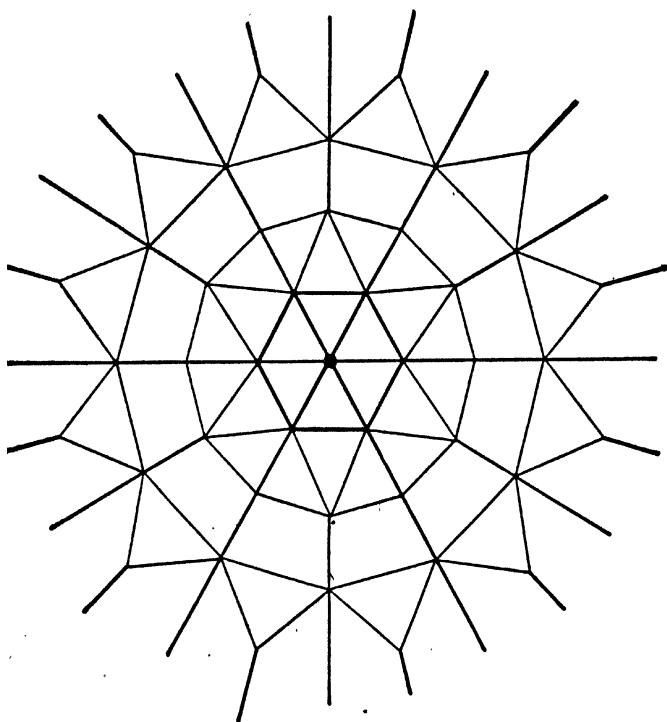
The atomic bomb, of course, makes the solar mirror superfluous as a weapon of war, and it is very probable now that it will never be built. But I have to defend Oberth against the accusation, made by several physicists, that he misjudged the theoretical requirements. When, in the summer of 1945, it became known that preliminary plans for a solar mirror had been found among German military documents, several "experts" who were obviously not very conversant with existing literature insisted that a solar mirror could not produce a sufficient concentration of reflected solar radiation, even if proper curvature could be achieved.

The criticism, condensed, amounted to the (incidentally correct) statement that it would be impossible to concentrate the light from a mirror five miles in diameter on one acre of land. The answer to this criticism can be found on page 354 of Oberth's *Wege zur Raumschiffahrt*, where he wrote: "The laws of optics provide that the reflected image of the sun, seen from a facet of the mirror, must appear at least as large as the sun itself seen from the mirror. If d is the diameter of the image, a its distance from the mirror, D the diameter of the sun, and A the distance of the mirror (or, which is virtually the same, of the earth) from the sun, we get

$$\frac{d}{a} \text{ larger than } \frac{D}{A}$$

If the mirror, for example, were 1000 kilometers (roughly 600 miles) from the surface, the solar image of each facet would have a diameter of 10 kilometers. If the solar images from all facets could be brought together, the solar energy would be concentrated upon an area of 78 square kilometers. . . ."

An area of about 30 square miles is not precisely a "point" as will be readily admitted. But theoretically that area is dependent only on the distance of the mirror from the surface of the earth. It will grow with increasing distance, but will not grow with increasing size of the mirror. Oberth, therefore, concluded the observations just quoted with the sentence, "since the reflecting surface can be



45. Mirror Net, after Oberth.

Professor Oberth wanted to anchor his space mirror's facets in a wire net opened by rotating it around its center. The single facets have to be imagined very large, about $\frac{1}{2}$ mile in diameter.

made suitably large, most colossal effects can be achieved." The minimum area might be about 30 square miles—but if the mirror is only large enough it can, theoretically, make lakes boil and melt steel in that area.

To reach the station, once established, with a synergic ascent, would require, according to Oberth, an ideal velocity of 8600 meters per second. Personally I feel that several factors would add considerably to this figure, but it might be used to gain a rough idea of the mass-ratios required for various exhaust velocities. For an exhaust velocity of 4000 meters per second the mass-ratio would

be roughly 9:1. For 5000 meters per second it would be just about 6:1, for 10,000 meters per second about 2.5:1, and for 20,000 meters per second only 1.5:1; in the latter case only one-third of the take-off weight of the ship would have to be fuel load.

I am at the end of my story now, the story of the development of the idea of space travel from earliest to modern times. But I know that there are a large number of questions in the minds of my readers. Most of these questions do not concern the straight technical aspects of these problems; they are concerned with the welfare of the people who may undertake these ventures, who may travel outside the atmosphere in large space rockets, possibly embark on a trip around the moon, and finally man the station in space. These questions are very natural because they are very human and for this reason they cannot be simply dismissed with the otherwise perfectly correct statement that a science capable of producing a spaceship, or rather the science which will produce the spaceship, will also be capable of taking care of its pilots.

But this answer has to be kept in mind from a somewhat different point of view. The questions about the welfare of the men in a spaceship can be answered today, but with today's answers. A few decades hence, when things will probably have progressed to the first manned space rocket, the answers will be different. Other and presumably better solutions will have been found in the meantime.

The first question usually concerns temperature. It is still in most people's minds that space is cold. Actually space is not "cold"; it does not have any temperature at all. Only material bodies can have a temperature. The spaceship, of course, will assume one—a temperature which strikes a balance between the heat absorbed and the heat radiated. The heat absorption depends mostly on the distance from the sun which for quite some time to come may be called "somewhere between Venus and Mars," or somewhere in the "temperate belt."

The balance between absorption and radiation can be influenced by artificial means; the simplest and easiest way would be to have one half of the passenger cabin painted dull black while the other half is polished to the greatest possible mirror brightness. (The fuel tanks have to be mirror bright all around.) If the shining (reflecting) half were turned to the sun, virtually no heat would be absorbed. If the dull black half were turned to the sun, all available

heat would be absorbed. Intermediate positions would produce intermediate results. Generally speaking it is apt to be rather too warm than too cold.⁴ Only when the ship is in the shadow (umbra) of a planet would a drop in temperature be expected, but such periods would be short.

The turning of the ship around on its long axis to regulate internal temperature as well as the turning of the ship around on its short axis to point the exhaust nozzles in the desired direction prior to a maneuver or correction could be accomplished in a very simple and somewhat surprising manner. If a wheel is turned inside the ship, the ship itself would begin to turn against the momentum of the wheel in the opposite direction. The proportion of turns would be in accordance with the masses involved. A wheel whose rim weighs, say, 10 pounds would have to make one thousand complete revolutions to cause the ship (which at that instant is supposed to weigh 10,000 pounds) to make one complete revolution in the opposite direction. A practical wheel for this purpose would be built like a bicycle wheel with a heavy metal rim, equipped with a hand crank, a differential gear, and a revolution counter. Three such wheels, mounted in such a manner that the three axes come together like the edges of a box would make it possible to turn and point the ship in any direction and position desired. Naturally this would not have the slightest influence on the direction of the movement of the ship; it would serve merely to swing the ship in the proper position. Of course one single wheel, universally mounted, would do the same, but would cause only one kind of turn at a time.

An important question concerning the welfare of the men in a spaceship is one that is usually not asked: the reaction of the human body to a prolonged absence of gravitational strain. Whenever the motors are silent, which is practically all of the time, the spaceship is in a "free fall" which may be directed toward the earth, away from the earth, toward the sun, or away from the sun—almost anything. But it is always a free fall, an unrestrained following of the orbit caused by the various gravitational fields and the rocket's action. What we called Condition (C) with regard to the station in space prevails in any spaceship as soon as the initial

⁴ According to a rough calculation it is apt to be some 75 degrees Fahrenheit.

ascent has been completed—roughly after ten minutes—and it keeps prevailing until landing maneuvers begin.

Since this condition occurs so rarely on earth, and only for very short intervals of time, we know very little about the physiological reaction to be expected. Oberth once undertook an experiment which consisted of taking certain drugs and then immersing his body into water of body temperature, and he found that the experience was not even unpleasant. But this experiment, of course, caused only the sensation of complete weightlessness and not the actual physical conditions, hence the reaction or rather lack of reaction of his body is not conclusive.

There is little doubt about the extremes as far as time intervals go. Short periods, a few minutes up to half an hour, are not likely to cause any reaction at all. It is also likely that this period may be prolonged by practice if some reaction should occur after several hours. There is also no doubt that a very prolonged period of weightlessness, lasting for many months or even years, will cause the muscle tissue to deteriorate since the muscles, at least the voluntary muscles, are not used.

The involuntary muscles are not likely to be affected. The job of the heart, circulating the blood through the body, will be about the same. The resistance which the heart finds in circulating the blood is mostly due to the friction of the liquid against the walls of the blood vessels, not to gravity. The same, with obvious modifications, goes for breathing, and the peristaltic movements of the stomach have nothing to do with gravity.

Some authors have worried about swallowing of food and drink and about the more delicate bodily functions, an unnecessary worry since none of these functions relies on gravity. One can eat lying flat, where gravity hardly plays a role, and it is not even unpleasant. One can even eat and drink upside down, swallowing against gravity. It is not pleasant, but it can be done. As for ejected waste matter, it actually is an ejection which also does not depend on gravity.

It is quite possible that the absence of gravitational strain will not cause anything more serious than a temporary nausea. But in case it does cause troublesome or even serious physiological reactions, a countermeasure can be designed. There exists a perfect substitute for gravity: centrifugal force.

It could be done in about the following manner: As soon as it has been established that the ship is in the proper orbit and that no corrections will be necessary for quite some time to come, the ship is divided into two parts of pretty nearly equal weight. One strong push, produced in any manner practicable, will make the two parts drift apart, and they are then connected only by a long steel rope. A sidewise push (rocket action) will send the two parts spinning around the common center of gravity which is located half-way between them if they are of equal weight. The resulting centrifugal force will replace gravity, and the spinning neither affects the orbit of the ship nor does it necessitate fuel expenditure until it is to be stopped.

However, there are some drawbacks connected with this. If we want to produce a centrifugal force equal to earth's gravity at the surface and if we use a 3-mile long rope, each part would have to travel 12 feet per second. A complete rotation would require 4335 seconds or 72¼ minutes, far too slow to produce dizziness from spinning. Observations, of course, would be difficult, if not impossible.

So far everything looks fine, but a 3-mile steel rope cannot be put away in a small locker. If we assume that each of the two parts weighs 20 tons, which would be correct for a large number of cases, the strain upon the rope would be half the total weight. A steel cable capable of bearing this strain—with a fair safety factor added—would have to be about ¾ inches thick and 3 miles of it would weigh around 13,000 pounds. If the cable were shorter, the two parts would have to spin more rapidly, but the strain on the cable would be less because it weighs less itself.

By making the cable only 1 mile long, by using a more suitable alloy than ordinary steel, and by paring down the safety factor—since the rope weighs less—you might be able to slash three quarters off those 13,000 pounds. But even 3000 pounds of dead weight are very unpleasant in any mass-ratio calculation. If we could do without the rope and without spinning, things would be much better. In that case only the gradual weakening of the tissue of the voluntary muscles over long periods would have to be prevented which can be done by regular exercise periods. Of course the exercises cannot be of the type involving weight lifting (the weight is the weight of your own body, or parts of it, if you use a "gadget-less" system) since weight does not appear. But steel springs and

rubber bands retain their resistance and one can still play one set of muscles against another.

The objection to 3000 pounds or more of dead weight obviously applies only to the rocket vessels. There is no reason why the sleeping and recreation rooms of the station should not be designed that way.

Before I go into the rather complex question of eating, drinking, and breathing, the known dangers have to be mentioned. "Known" dangers means just that—the dangers we know of and can think of. If there are others, they have to be of a type which so far have escaped detection completely—chances are decidedly in favor of the assumption that there are no such "other" dangers.

One known danger comes from the short radiations, ultra-violet and shorter, of the sun and meteorites. The metal hull of the ship—or of the station—will protect the crew from all short radiations.⁵ The weak points are the windows. It is significant that all the "early" books about the problem, those written between 1925 and 1930, are evasive about that question. I remember that I was once asked about it after a lecture and that I had to reply that one would have to wait for favorable developments in that respect.

In the meantime these favorable developments have taken place. High-altitude flying has taught a number of valuable lessons and has stimulated chemical research to solve the problem.

In the first place, glass has been replaced by transparent plastics which are far superior mechanically. But the customary transparent plastics list it as one of their advantages that they do *not* shut out ultra-violet rays. This is an advantage at and near sea level, where the dosage is small. But in high altitudes, where the thickest part of the atmospheric blanket is lacking, there is far too much ultra-violet for good health. It did not take long, after this was realized, to develop a special type of transparent plastic which is almost opaque to ultra-violet without impeding the passage of visible radiations. For use in open space even this new compound is not opaque enough, but the quick partial solution of the problem indicates that a full solution is possible.

The danger from meteorites is far more substantial and cannot be combatted in so easy a manner as the ultra-violet. In fact there is little that can be done about meteorites at all. Detection of a

⁵ The very penetrating "cosmic rays" are excluded from this statement, but there are not enough of them to present a problem.

large meteorite might be possible by a radar-type instrument, but it would probably miss the small and much more numerous meteorites.

Even if the instrument did not miss them, the detection would not be of any help. Detection does not mean that the orbit of the meteorite has been established. It would be a major job to find out whether the orbits of the meteorite and of the ship intersect at a point where both will be at the same time.

Thus the value of a detecting instrument begins to look analogous to the value of books according to one certain old Caliph. He said that he could not see any value in books. Either they contradict the *Koran*, in which case they are evil, or else they don't contradict the *Koran*, in which case they are not needed. Either the meteorite misses the ship, in which case it is just as well not to know it, or else it does not miss, in which case foreknowledge of the event is useless because the ship cannot swerve. And the station could swerve even less than a ship.

No doubt there is a danger factor there and all we can do is to estimate the probable frequency of such an event. The earth, astronomers estimate, is hit by some two million meteorites every twenty-four hours. The vast majority of them burns up in the atmosphere; an average of two out of the two million reach the ground. To a spaceship, or to the station, even the small ones would constitute a danger, but that figure cannot be applied to a spaceship as some critical authors have done in the past. The earth presents a target several thousand billion times as large as the largest conceivable ship. And although most meteorites do not so much fall onto the earth as they run into it or the earth runs into them, the gravity of our planet plays a role too. This second factor is missing completely in the case of a ship.

The figure given for the earth is, therefore, only misleading and should be discarded. But another way of estimating the danger can be tried.

In astronomical books it is mentioned that the fall of the Leonids was unusually beautiful in 1866. This simply means that in that year the earth ran into an unusually dense sector of that swarm of meteorites. But it could be calculated that, by terrestrial standards, even the densest sections of that dense sector were simply "empty." The minimum distance between two particles exceeded 110 kilometers or about 70 miles.

In order to get a more recent estimate, one of the members of the VfR approached Professor Graff of the Observatory near Hamburg in 1928. Graff replied: "Even in very dense swarms there is hardly one particle weighing less than a gram [$1/28$ of an ounce] in a space of 100 cubic kilometers, a space immense beyond imagination. As far as large meteorites are concerned, the danger of collision becomes zero."

Making some unfavorable assumptions, one can calculate that we would have to send about five hundred thousand rockets around the moon to be sure that one of them would be hit by a meteorite. The danger factor, it may safely be concluded, is quite small.

However, it does exist, and it is the only danger that is not due mostly to the imagination. But since when do we live in an age where no ship is ever wrecked in a storm, no railroad train ever suffers an accident, and no airplane ever crashes?

If a meteorite did hit the passenger cabin of a ship, it would pass through the metal walls—probably consisting of an aluminum-beryllium alloy—as easily as a high velocity rifle bullet passes through an empty cardboard box. Still this does not necessarily mean the death of the whole crew. Because of its rapid passage, the meteorite would produce two holes of exactly the size of its own diameter. Naturally the air would escape through these holes, but it would not happen instantaneously. In fact the drop in air pressure may be the first warning sign.

Now we get into a whole complex of questions. The mechanical part is comparatively simple. If the walls of the cabin are comparatively bare, as they should be, the holes will not be too difficult to locate. A small patch of sheet rubber would close the hole; the air pressure in the cabin itself would hold the patch in place until a real repair job can be undertaken. But such an event has physiological implications. Supposing that the air pressure drops to half its normal amount between the accident and the emergency repair with small slabs of sheet rubber. There would still be air enough left for breathing (uncomfortable breathing) but the rapid decompression might have serious consequences. The occupants may come down with a case of "diver's sickness," commonly called "bends."

"Bends" is caused by rapid decompression of any description, but the real cause may be described as "bubbles in the blood," nitrogen bubbles, to be precise. The nitrogen of the atmosphere

has the habit of dissolving in the tissues and in the blood. As long as the pressure stays normal this saturation with nitrogen is of no consequence whatever. But when the pressure is released, or better relaxed, the nitrogen emerges and forms the dangerous bubbles constituting the cause of the bends. Elaborate tests (a summary of which was published in *Science* [February 27, 1942], No. 2461) have shown that the bends might be avoided if the body is saturated with oxygen for a period of time before the decompression occurs. Unfortunately the "period of time" is long, at least five hours, and breathing too much oxygen is not at all healthy either. But there exists another and better substitute for nitrogen: helium.

Helium, chemically even more inert than nitrogen, does dissolve in the body to a certain extent, but it is much less soluble than oxygen, roughly one fifth. Conversely, the process of bubble formation under decompression is much milder; in fact it needs an extreme case to occur to a health-impairing extent. Diving tests with rapid ascent have shown that experienced divers at least, emerging in a helium-oxygen atmosphere, can sustain decompressions which would have killed them if the atmosphere had been a nitrogen-oxygen mixture. It becomes clear, then, that the atmosphere inside a spaceship cabin should be a helium-oxygen instead of a nitrogen-oxygen mixture.

This again is a point where recent developments evolved for high-altitude flying permit us to say more than could be said ten years ago. Supposing the meteorite which pierced the cabin was very small, so that the holes it made were like pinpricks? Air would escape slowly through these holes and the decompression would be so slight that it might pass unnoticed for a long time. A great deal of oxygen atmosphere could be lost in this way.

A small gadget, worn in the ear, answers this problem. The gadget operates by sending a tiny beam of light through the ear lobe. The color of the blood changes very slightly with the varying oxygen content of the atmosphere, far too slightly to be discovered by the eye. But the photoelectric tube connected with the gadget can see and distinguish two million shades of color, and it announces these changes of shades by means of a pointer on an instrument dial. In that manner small losses would be discovered very soon, and not only losses, but also any other changes in the spaceship's atmosphere.

Now we come to the problem of fueling the body of the pilot.

The human body needs three things: air with oxygen in it, water, and food. And when it comes to spaceships most people invariably assume, as Dr. Moulton did, that a full supply of oxygen, food, and water has to be carried along. This conception leads to a short calculation and the calculation leads to the verdict that it is too much to be carried. Even under this assumption the verdict is not quite justified, and all of Dr. Hohmann's calculations were made with such an assumption. But the assumption is wrong too, especially as applied to one of the three factors: food.

It is amusing to see that fiction writers also tripped up on this problem. They considered that so and so much oxygen had to be carried, plus a fair amount of soda-lime to absorb the carbon dioxide and the moisture. They decided that so and so much water was needed. But they started the idea of a "meal in a pill" to save at least the room which would be occupied by a decent food supply.

The meal in a pill does not work. As far as the essentials of human nutrition go, you can go down to pill size only for the things that are usually in pills anyway: vitamins and minerals. But the amount of carbohydrates needed per man and day is around 2 pounds, and 2 pounds is 2 pounds and does not get smaller by saying so. There are some other things besides carbohydrates, minerals, and vitamins which have to be supplied, so that it is a good bet to say that meals will continue to be meals as we know them. Of course you can save a great amount of bulk and weight first by trimming off nonessential parts as is done anyway for canning. A large variety of foodstuffs can be dehydrated which saves even more weight. And the dehydrated foods should be somewhat compressed as has recently been learned, since this not only saves additional bulk (though no weight), it also makes the food keep better since the oxygen of the air has no longer easy access to the interior.

Food, as I said above, will have to be taken along—a full measure of it. But that does not apply to the water and to the oxygen. In these respects the spaceship is, or can be made to be, a "closed system"—the equivalent of a well-balanced aquarium with fish and plants in it. Only the ship would take on a more "scientific" and less "natural" shape—in some respects.

An allotment of 1 gallon of water per man per day would be more than enough under any circumstances that may be encountered. But while the body does need that water desperately, it does not keep it. It throws it off as a matter of course. As a matter

of fact, the body produces some additional water of its own. The "combustion" of food in the body proceeds along a long series of complicated chemical reactions, but some water is one of the end products. The water leaves the body in various ways: roughly half of it by way of natural discharge, the other half by way of expiration and skin evaporation. If it is hot, the skin evaporation grabs a much higher percentage of the total.

The water lost by skin evaporation and expiration enters the air and has to be removed, but there is no need for clumsy chemical methods out in space. Oberth suggested a simple mechanism, consisting in the main of a long tube leading from the cabin to the outside. The tube was to go in a tight zigzag along the dark side of the ship, then pass around to the illuminated side, describe another zigzag line of the same length as before, and return to the interior. The reason for this device is simply that it is very cold inside that tube on the dark side, cold enough to freeze the moisture out of the air and to condense the carbon dioxide gas into "dry ice." The oxygen and nitrogen (now replaced by helium) would not lose their gaseous state, would be heated to ordinary temperature in the other zigzag, and would return to the cabin. Only additional oxygen and an occasional cleaning of the tube would be required.

Oberth did not say so—possibly because he described that mechanism in an example of a moon journey which would be too short to go in for elaborate "saving"—but it would be wasteful to throw the ice and "dry ice" away. The ice could be melted, distilled, and washed and it would then be very pure distilled water which can go through the same process again, and again, and again. The water allotment could be cut down to about a quart per day per person. The water fits perfectly into the closed system.

The carbon dioxide does too, to a certain extent. If the trip is a question of many man-days, there exists a mechanism which is much lighter than liquid oxygen that can be carried along for breathing purposes. That mechanism is the living plant. Plants use carbon dioxide and exhale oxygen; they form the other half of the closed system started by man's breathing of oxygen and exhalation of carbon dioxide. The question is whether plants produce enough, say by weight or bulk, to compete with the weight and bulk of liquid oxygen. The answer is that they do, provided the period under consideration is not too short. For one, two, or even

three weeks liquid oxygen is superior; from then on plants win.

But there are some specifications: not plants in general. Growing plants, fast-growing plants, especially starch-producing plants, are best. They do a little better if the atmosphere in which they grow contains more carbon dioxide than the atmosphere of earth, but the percentage used in experiments would still not hurt human beings. German plant physiologists singled one plant out as being especially effective: a growing pumpkin. They found that 1 square meter, or about 11 square feet, of leaf surface can supply the oxygen needs of a resting person. Other botanists, to whom I talked about this, swore that certain water plants must be more effective. It probably would not take much experimentation to find a plant which is the best all around: fast growing, with large leaf surface (that does not mean large leaves), and unaffected by its surroundings.

The current minimum estimate is that each cubic meter of plants can supply the oxygen needs of at least two people doing a normal amount of non-strenuous work. And they could do it, not for any limited time, but indefinitely, as long as they stay alive.

Liquid oxygen for breathing, therefore, would need to be carried only for emergency purposes and for use in what has become known as a "space suit" which is a pressure-proof diving suit with an electric heating and a small reaction mechanism, to be used for "outdoor work" around the station or for inspections of the outer hull in the case of a spaceship. And for leaving the ship on the moon, if a landing should be in the plans.

These are the answers I promised to give. They are, I repeat, the answers of today and they will probably not be the same fifteen years or so from now. But they show that these questions can be answered.

There is one more answer which I separated from the others because it will *not* be subject to change. The problem of navigation, or astrogation if you prefer the term. A spaceship, once launched into an orbit, is not in danger of straying from its course; there is no weather in space and the equivalent of currents are the gravitational fields in and among which the ship is coasting. While there is absolutely no chance for "straying" in that sense, there exists the chance, of course, that the ship is not quite in the proper orbit, and that point will have to be checked. It can be checked

very easily—easy in principle, at least—by means of celestial navigation, used today on every airplane.

The principle, as used by aviators, is this: at a given moment a certain star must be vertically over one point of earth. This point is called the "substellar point" and if an airplane found a star directly overhead, the whole problem would be solved; the plane would be over that substellar point which can be looked up in a table. Most of the time, however, the star is not overhead but at an angle which has to be measured. The first measurement results in a circle, drawn on a globe around the substellar point, with the angular distance found by measurement. The plane is, must be, at one point along that circle. Then the maneuver is repeated with another star which produces a second circle, crossing the first one in two points. The plane is in one of these two points and, since they are usually a thousand or more miles apart, there can be no doubt which one of the two it is.

Actually the navigator, just because he knows approximately where he is, does not draw full circles but only two short straight lines on a map. The two lines represent short sections of the two circles. Their crossing marks the position of the plane and is called a "fix."

In that form, celestial navigation cannot be used for purposes of space travel, but it can be easily adapted. The recipe was written some time ago by a professional astronomer, Dr. R. S. Richardson.⁶ It works like this: First the astrogator finds the star Regulus which happens to be large and which also happens to be situated nicely in the plane of the solar system. He measures the angle formed by the sun, the ship, and the star Regulus. Since Regulus, to all practical purposes, is motionless, the angle sun-ship-star informs the astrogator about his position in space. The astrogator now knows the position of his own, or rather his vessel's *radius vector*. What he needs to find out next is the length of the *radius vector* and this is established by constructing a triangle of sun, ship, and a planet, usually the target planet. Of that triangle he knows one side, the distance of that planet from the sun for that day—it will be in his *almanac*—and he can measure or deduce all three of its angles.

⁶ In an article "Space Fix," in Street & Smith's *Astounding* (March 1943). This magazine, although classified as a "pulp," carries quite a number of articles by professionals, dealing with matters somewhat outside the scope of professional journals.

It is easy to calculate the length of that side of the triangle which represents the ship's distance from the sun.

Of course special instruments combining high accuracy with simplicity of operation will be developed, not only for measuring the length of the ship's radius vector but for other purposes too. The central piece of the instrument set will have to be one which is a counterpart to the gyro horizon of the airplane, a steady and unchanging frame of reference for which the plane of the earth's orbit will probably be chosen. To produce the "gyro ecliptic" is merely a matter of design, not involving any special difficulties.

While the length and position of the radius vector are the important things to know during the trip itself, they become unimportant once the target planet is near. When Mars, for example, looks twice as large to the pilot as the moon looks to us, he will be more interested in knowing how far he is from the planet and how the relative velocities compare with calculation. Now, of course, it is not difficult to tell how far a planet is away once its true size is known. The diameter of the planet forms the base of a very long triangle of which two things are known: the true length of the base (from the astronomical handbook) and the angle at the apex (from direct measurement). To find the distance from apex to base is elementary geometry and the pilot will not even have to make the calculation, tables will be ready for this purpose. All he will have to do is to measure the angle.

And to check the accuracy of his measurement he will have another device at his disposal, the radar altimeter. It is a recently developed electronic counterpart to a twenty-five year old instrument evolved originally for ships and submarines. Its inventor, one Dr. Behm, called it the *Echolot* ("echo sounder") and that is just what it was. A surface vessel equipped with this instrument carried two small devices outside below the water line. One was a noise-maker, a kind of pistol firing a small blackpowder cartridge. The other was a recording microphone. When the cartridge was fired, the microphone recorded the sound while the sound waves traveled on. Hitting the bottom, they were reflected and came back as an echo, to be recorded again. The time interval between the two recordings indicated the depth at that spot.

Since it was first invented Dr. Behm's old *Echolot* has been developed into the highly sensitive *Sonar*, but it could not be adapted directly to airplanes, partly because of the engine noise, partly

because there were too many sounds and cross echoes present in the air. High-frequency radio waves came to the rescue and the radio echo, substituting for the sound echo, produced the radar altimeter, which will measure the distance from an airplane to the ground at any moment.

That instrument can be applied directly to interplanetary use. That it does not make any difference to the radar impulses whether they travel through air or through empty space, or whether they have to bridge 20,000 feet or 200,000 miles has been proved by the much-discussed "radar shot to the moon," accomplished by the U. S. Army Signal Corps in January, 1946.

The instruments needed for space travel can be built. . . .

CONCLUSION

I HAVE now reached the end of my story.

And I believe that I have shown that the idea of space travel has by now reached a rather high state of perfection. There is not the slightest doubt any more about the validity of rocket theory. There is also no doubt any more about the requirements, the demands that have to be made of men and machinery. Needless to say, we are still somewhat uncertain about minor points and specific problems. But the important thing is that this uncertainty applies *only* to specific points and to minor problems.

It does not apply to the fundamentals, and there is nothing to which there is not an answer of some kind. Nowhere in the vast ~~expanse~~ of this problem could anything be discovered which looks like a really unsurmountable obstacle. There are plenty of difficulties, numbers of troublesome corners, mountainously high requirements. But nothing that could not, in one way or another, be approached and be brought more closely to a solution, even without placing too much hope in atomic energy.

In short, it looks as if that great old dream is not a dream after all. It looks as if it were something that can be done.

But there is one more question to be answered. And that question reads: *why* should we do it, why should we try for space travel?

Those semi-philosophic statements like Ziolkovsky's about the inescapable logic of man's conquest of space after all of the earth has been conquered do sound very nice. They are possibly correct, too, but that question remains, with a slight shift in emphasis.

Why should *we* try for space travel? Why not later generations who will find the job easier?

The answer to that question may not be convincing if you don't want to be convinced, but it is a simple answer. Somebody has got to start at some time, and we may as well get the glory for our own century.

The businessman will be quite willing to accept the glory which goes with the conquest of space rather than leave it to anybody

else. He is even ready and willing to buy it, provided it can be bought at a reasonable price.

"Reasonable" means either "small," or it means a price which yields financial returns. The first is certainly not the case. How about the financial returns?

I don't mean the meteorological rocket here. The commercial usefulness of that will be admitted readily.

I mean actual space travel, space travel with its long period of development and with its incredible amounts of money involved, all called "initial outlay." What are the financial returns that can be expected from that?

The first trip may expect to pay part of its cost out of curiosity value. Pieces of lunar rocks, samples of lunar sands, anything lunar at all will bring fabulous prices. But only once.

• Later on commercial possibilities of that kind are nil. We cannot expect to find anything on the moon, generally speaking, that cannot be found on the earth. We cannot expect to find anything valuable enough, barring pure platinum and highly concentrated radium salts (and there is not much hope for either of these things) that can pay for its incredible haulage.

It cannot be a substance of any kind that can be expected to pay. It can only be something intangible, not involving haulage, which is, at the same time, more valuable.

There is something like that: Knowledge.

The station in space, the spaceship circling the earth, is, as we have seen, a super-laboratory for any branch of physics and chemistry and for some branches of the biological sciences. It is a laboratory with completely new facilities, offering absolutely new conditions. It offers a temperature range from the intensity of concentrated sunbeams to cold near that lower limit which scientists call absolute zero. It offers a vacuum better than any that can be made on earth, literally limitless in size. It is free from gravitational strain, but you can produce any gravitational strain you want to have for some reason.

Since the conditions are new, new results are certain to be obtained. It is a place where pure research can be counted upon to furnish new discoveries. And new discoveries, the discoveries of pure research, are the most valuable asset of any industry.

The station in space promises many new discoveries. It is not impossible that a single one of them will pay for everything.

Appendix 1:

ROCKET AIRPLANES AND ROCKET-ASSISTED TAKE-OFF

The story of the rocket airplane is the story of a sideline of rocket theory, and the rocket airplane itself is, in a manner of speaking, a by-product of the pursuit of rocket research. It may sound like an obvious thought to take a rocket motor, once you have it, and to build an airplane around it. Actually this idea, which occurred again and again to literally scores of people, is beset by extraordinary difficulties. And even though rocket airplanes have not only been built but have actually been flown operationally during the Second World War, the problem is by no means solved, especially for non-military aircraft.

The late Max Valier liked to think that the rocket airplane could be produced by simple substitution of rocket motors for internal combustion engines in existing airplanes (the airplanes of 1928!) and that it was merely a question of adding rocket motors and of reducing wing surface in order to arrive at a man-carrying space rocket in the end. Even though Valier's presentation of what he took to be a technological problem was universally rejected, the first experiment in all history of a man-carrying rocket-propelled airplane can be traced back, in the end, to Valier's publicity campaign.

That experiment took place in the summer of 1928, and it was an offshoot of the Opel experiments initiated by Valier. The airplane was a glider of the then novel canard type—which to the uninitiated always looks as if it were flying backwards—and it made its first and only flight on June 11, 1928, from the Wasserkuppe, one of the Rhön Mountains in western Germany.

The experiment was a joint venture: Sander manufactured the power rockets used, von Opel paid for them or at least contributed part of the expense, and the *Rhön-Rossitten Gesellschaft*, a German glider society which derived its name from the sites of its two most important camps, furnished the glider. It also provided a number of glider models which were tested before the full-size glider was risked. The experiments were directed by A. Lippisch who reported on them in a German aeronautical journal¹ while the pilot of that first rocket glider, Friedrich Stamer, was present and assisted during the preliminary tests.

The assortment of rockets furnished by Sander for the experiments consisted of five types, three for the model gliders and two for the full size glider.

¹ See *ZfM* (Munich), vol. 19, No. 12, dated June 28, 1928.

ROCKETS

TYPE	BURNING TIME	THRUST	
<i>For the models</i>	(sec)	(kg)	(lb)
Bored rocket	3	75	165
Bored rocket	3	175	385
Solid brander	30	5	11
<i>For the glider</i>			
Bored rocket	3	360	790
Solid brander	30	20	44

Naturally the aviators made the model tests first. The model chosen for the experiment was a tailless type called *Storch* (stork) with a wing span of a little over 7 ft and a weight of about 30 lb. (It is not stated whether the rocket was included in that weight.)

For the first experiment one of the powerful 165-lb-thrust rockets was used. The result was what should have been expected: the powerful rocket regarded the wings and ailerons of the model as a mere hindrance to proper performance; it tore the model vertically up into the air until it was burned out and then let it drop. And it did drop, since it was in an unstable position. When the second experiment, with one of the small solid branders, was almost as bad a failure, Lippisch realized that the models were poorly adjusted for that type of propulsion.

In the third experiment, also with a small solid brander, the model was launched from a small wooden rack by a rubber rope which was released automatically. The result looked encouraging: the model made a long and perfect flight. The fourth model experiment, as well as the fifth, were made with the most powerful rockets that were available for the models; they had to stand an acceleration of 12g and there was some doubt whether they would.

Test 4 was very much a repetition of test 1. The model left the rack "like a projectile," as Lippisch put it, and climbed to about 300 ft. Alone, the rocket would have attained about ten times that height; the wings did nothing but provide a lot of unnecessary air resistance which cut down efficiency. For some reason they stayed on and held together. At 300 ft, when the rocket was burned out, the model turned on its back, flew for a few seconds in that position, and then slipped over one wing, assuming normal position which resulted in a long glide. In test 5 the wings gave up; they were not designed for an acceleration which made it attain 350 mph in less than 3 sec. They simply broke and the model fell vertically to the ground like a stone when the rocket was exhausted.

These tests gave a few hints of what was to be expected with the glider, and the experimenters followed the most obvious of them: they discarded the 790-lb-thrust rockets, using only two solid branders of 26 and 33 lb thrust, respectively. Since it was expected that the pilot might be excited and make mistakes, the electric ignition of the rockets was rigged in such a manner that he could not ignite both of them simultaneously, no matter what he did wrong.

This was a nice precaution, and the planned procedure was that the glider should be launched by the customary rubber rope. The pilot was not to ignite the rockets until he was free of the rope and safely in the air.

In spite of all these arrangements the first two attempts failed. In the first something went wrong with the rubber rope and Stamer did ignite one of the two solid branders before he was in the air. It just burned out and nothing happened. That it burned without any mishap may have quieted the pilot somewhat, because during the second test he did get off the ground. But he found trouble balancing the glider and landed after a flight of some 700 ft without igniting the second brander. The glider was then brought back to the starting point and the second brander was taken out. After inspection of the ignition system the glider was fitted with two solid branders of 44 lb (20 kg) thrust each.

I'm now quoting from Stamer's report:

The plane took to the air by means of the rubber rope, aided by one rocket [brander]. After flying for about 200 yards in a straight line—I noticed a slight climb—I made a curve of about 45 degrees to the right and flew another 300 yards. Then I turned again to the right, again about 45 degrees. Immediately after the [second] turn the first rocket ceased burning and I ignited the second. . . . This time I flew about 500 yards in a straight line, made a turn to the right of about 30 degrees and landed the machine after another 200 meters, just a few seconds before the second rocket was exhausted.

The distance covered was just about one mile and the time needed was a little over one minute. Asked about his impression, Stamer declared that the flight had been "extremely pleasant" and added, "I had the impression of merely soaring, only the loud hissing sound reminded me of the rockets."

For the second flight it was intended to climb over a small mountain.

The launching went all right and while the plane took to the air I ignited the first rocket. After one or two seconds it exploded with a loud noise. The nine pounds of powder were thrown out and ignited the plane instantly. I let it drop for some sixty feet to tear the flames off. After succeeding in that I landed the plane without mishap.

Just after landing the second brander caught fire but fortunately did not explode. The fire had damaged the glider to such an extent, however, that extensive repairs were necessary. The *Rhön-Rossitten Gesellschaft* did not resume the experiments; it seems that its leading men had come to the conclusion that rockets did not serve their purpose.

The *Rhön-Rossitten Gesellschaft* did have a definite purpose in mind when making these tests; they had not just done it to please von Opel or anybody else. Following the trend of an oft-made suggestion, they had hoped to use rockets in lieu of the rubber rope or the car tow to get their gliders into the air. Both these methods, the rubber rope and the car tow (the latter was

rarely used by that society because of the mountainous territory in which they worked), were good and inexpensive methods, but they had a disadvantage: a glider pilot could not go out for a flight alone. Without help he could not get into the air; he needed either at least eight men with the rubber rope or else a car and a driver. If rockets had proved satisfactory that problem would have been solved. And since the rockets did not weigh very much it would have been possible, theoretically, to carry two or three of them along for other take-offs after intermediate landings.

The main reason for discontinuing the experiments was not so much the fact that the first experiments had not come off too well, but the ever present danger of explosion which increased with the age of the rockets. Since then, as explained in chapter 8, the problem of the explosion-proof powder rocket has been solved satisfactorily for military purposes, so it might be possible to resume glider experiments with these improved rockets.

After the *Rhön-Rossitten Gesellschaft* had abandoned the project it was taken up by the Raab-Katzenstein Airplane Company at Kassel. This firm set out to build a tailless plane similar in design to the small Lippisch stork model, but large enough to carry a pilot and possibly even a passenger. For some unknown reason the first tests were failures and Raab-Katzenstein gave up; possibly or even probably the German army intervened. But Fritz von Opel, who had somehow been connected with that attempt too, was not so quickly subdued; his early doubts had been replaced by the conviction that the problem could be solved by sufficient perseverance. He had a new rocket glider built for himself.

It was ready for flight testing on September 30, 1929. A wooden take-off rack 70 ft long was used, but there was no rubber rope or launching device; the glider was to take off under rocket power too. The first two tests, made during the early forenoon of the day mentioned, were not successful. The rocket batteries did not develop enough power to get the plane into the air. It just made short jumps from the end of the cradle. Von Opel had the rocket batteries changed and made another, successful attempt in the afternoon. Von Opel made a flight lasting about 10 minutes during which he attained a top speed of about 100 mph. The plane had a high landing speed (70 mph) for its weight, which was some 600 lb including the pilot, and its construction was apparently not quite rigid enough for the abuse it had to take. It also seems that the wings caught fire in the air; at any event the plane was very badly damaged during landing and was useless afterwards. An eyewitness stated that it seemed like a miracle that Opel could have even escaped with his life; actually he was not only not injured but unhurt.

It was Opel's last attempt in rocket research.

A few similar experiments followed in the wake of the *Rhön-Rossitten* and Opel flights in Italy three years later. In 1931 reports came that an Italian

engineer by the name of Ettore Cattaneo had built and tested a 620-lb glider-like airplane at the airport of Milan. Since these reports spoke of high-power rockets for take-off and of less powerful rockets for maintaining the flight, Cattaneo probably followed Opel's example closely. In one of the tests the craft remained in the air for 34 sec, traveling a distance of 1 kilometer or about $\frac{2}{3}$ mile.

It goes without saying that these rocket gliders of Lippisch, von Opel, and Cattaneo were not the first projects of their kind, they just were the first to be actually built and flown. There had been many earlier projects, not even counting those mentioned in chapter 4 which were conceived at a time when the internal combustion engine did not yet exist and where the choice of a power plant was, consequently, not a matter of free choice.

Among the earlier projects there had been one by a Russian engineer, Fyodor Geschwend of Kiev, who had dreamt about a winged railroad car propelled by a steam jet. There had been another one by a German inventor by the name of Wilhelm Gaedicke who wrote under the *nom de plume* of "Engineer Crassus" and who had advocated a helicopter with a multibladed rotor, driven by the reaction of an exhaust jet of air and illuminating gas. A similar jet, attached to the suspended cabin, had been projected for forward movement. There had been the flying torpedo of Alexander Gorokhov, with three exhaust jets on either side of the body and with wings so small that they were more like large stabilizing fins.

Most important there had been the suggestions of René Lorin, published in a series of loosely connected articles in the French aviation magazine *L'Aérophile*, beginning with the year 1908. As far as the aerodynamic features of his aircraft were concerned Lorin had been groping around, as was logical for that time. But he did have a sound idea of what he wanted to use for a rocket motor. It was a normal six-cylinder in-line engine which Lorin wanted to build so flat that it would fit into the wing of the airplane—what is now called a "pancake engine." An exhaust nozzle was to be attached to each cylinder and there was to be one engine in each wing, so that the plane would be propelled by a constant series of exhaust blasts.

Lorin's critics had to admit that the scheme looked as if it would have a number of minor advantages. There were no drive shafts and no gears. There were no propellers, and since the wooden propellers of those days were hardly very trustworthy their elimination looked like another advantage. It all apparently added up to a weight-saving power plant. There was only one thing wrong with it: the Lorin scheme, with its several minor advantages, lacked a major one. That major advantage was on the side of the engine with drive shaft and propeller.

Lorin had been caught on that dangerous ground where the two sciences of rocket propulsion and of aerodynamics are supposed to merge but show, instead, a remarkable tendency to clash.

The facts that get into the way of the rocket airplane designer are these: a rocket motor produces a very powerful blast of high velocity but of low mass. Neither the exhaust mass nor the exhaust velocity changes whether the rocket is moving or not. But the utilization of the rocket exhaust is a matter of vehicle speed. The faster the rocket motor is permitted to move, the higher is the over-all efficiency at which it will operate. Generalizing the rather complex problem somewhat, it may be said that the effort should be to match the velocities of the rocket (or the things propelled by it) and of the rocket exhaust.

It is this requirement which causes virtually all the difficulties, simply because the exhaust velocity of a rocket is so high. No wheeled vehicle could ever move fast enough for rocket propulsion, and as regards airplanes it was considered doubtful for a long time whether they could move fast enough. They certainly did not in the days of Opel—not to speak of Lorin—and they still don't but it now looks as if, one day, they might. The lower limit for really efficient operation may be considered to be 1800 mph. That is still three times the speed of the fastest jet planes of today and it could be done only in altitudes where no jet unit would be able to "breathe." But it does not sound impossible after recent experiences.

To go back to Lorin's rocket airplane scheme. Lorin did not know why his proposed plane would be inferior to propeller aircraft, where the propeller creates a "jet" of large mass and low velocity. But only a few years later engineers began to realize the real reasons, the gaping abyss between rocket exhaust velocity on the one side and airplane speed on the other.

There were two ways to bridge that abyss. One was to increase the speed of the plane. The other was to reduce the velocity of the exhaust. Complete bridging would probably require both.

In 1917 O. Morize of Châteaudun, France, proposed the first power plant for airplanes which was supposed to help to bring the two, airplane and reaction-propulsion, together. By means of an engine-driven compressor, fuel injection pumps, and a combustion chamber with exhaust nozzle, Morize first produced a rocket exhaust. But then he used a thrust augmentor on it. A thrust augmentor is a device which resembles a set of curved lamp shades, growing successively larger and held together by flat braces so that air can pass between them. When a high-speed blast goes through the center of this device this is just what happens; the fast jet sucks air in through the spaces between these nozzle rings, and the air adds itself to the fast jet, increasing its mass and slowing it down at the same time.

Morize, it appears, never built such a power plant, but it sounded like a possible solution of the problem of utilizing a rocket exhaust, and another Frenchman, Henri F. Mélot, made the Morize scheme practical. He dispensed with most of Morize's equipment and took two cylinders which he fitted end to end. Fuel inlet ports and spark plugs were placed at either end of the two-cylinder assembly. Inside there was a piston, but it had no connecting rod, it

merely shuttled back and forth to provide compression. The exhaust from either end of the double cylinder escaped through a tube into one common "buffer chamber" to which the exhaust nozzle was attached. The result was an intermittent rocket blast achieved by simple means—means simpler than those of Morize, at any event—which then was sent through a thrust augmentor.

Mélot did more than draw a nice design and write about it in *La Science et la Vie*. He actually built his motor. He actually made it work too. It was difficult to get it started, but once it was running it kept running. After some practical results had been accumulated, Mélot calculated that two somewhat enlarged engines of his kind would be capable of propelling an airplane of then customary dimensions. He experimented during the period from 1918 to 1920—and resumed experimentation again a few years later—but it seems that he never progressed much beyond his original success. There were numerous speculations at that time as to the reason for no further and impressive news from Mélot. These speculations ranged from a suspicion of plain failure to an assertion of marvellous success with resulting purchase by the French War Ministry and inevitable military secrecy. The actual explanation of the great mystery is quite simple: there was no reason to replace the well-known and steadily improving internal combustion engine with a new and insufficiently tested device. Airplanes cruising at speeds from 100 to about 130 mph at their very best did not need a new type of engine which at some future date might possibly prove superior to the then known engines.

Up to the time of Mélot the story of the (attempted) rocket-propelled airplane had progressed in a straight line, from inventor to inventor, from project to project, from theoretical improvement to theoretical improvement. But then things began to branch out, mainly because of the realization of the efficiency question. One set of projects held on to the rocket as propulsive mechanism and saw the solution of the efficiency question in a sufficiently high speed. The other set of projects accepted whatever speeds seemed reasonable and, like Mélot, tried to adjust the rocket to the airplane rather than the airplane to the rocket. The latter resulted in what is now commonly known as jet propulsion.

While the story and the problems of jet propulsion are outside the scope of this book, a few words about the differences and similarities of rocket and jet propulsion are needed.

In both, the movement of the airplane takes place in accordance with Sir Isaac Newton's Third Law of Motion. In that respect the two are alike and one may say that a jet unit is a rocket motor which gets its oxygen out of the air and which is rather complicated mechanically for this reason. The statement can also be turned around to read that a rocket motor is a jet unit which is greatly simplified by carrying its own oxygen along.

The distinction between jet propulsion and rocket propulsion seems to be easy for that reason, but intermediate designs like Mélot's require a more careful phrasing. One may be tempted to take the chemical nature of the

exhaust jet as the determining factor by saying that we have rocket propulsion if the exhaust jet consists *solely* of combustion products, as with Lippisch's rocket glider. Since Mélot's exhaust jet contained atmospheric air, partly from the air intake of the carburetor but mostly from the action of the thrust augmentor, his scheme is to be classified as a jet propulsion scheme.

But how would he classify a reaction airplane engine which is based on the alcohol-burning motor of V-2? For use in an airplane, where much longer burning times would be required, separate water injection would be a prime requirement for cooling. Or else the motor might be operated on a 50/50 alcohol-water mixture for the same reason. Then we would have an exhaust jet consisting of combustion gases plus water (in the form of vapor) but it would still be rocket propulsion. Evidently the chemical nature of the exhaust is a poor criterion for classification.

Still, the problem is simple; the point is not that water was mixed into the exhaust, the point is that it was water which had been carried along by the plane, while Mélot's additional air had not been carried along.

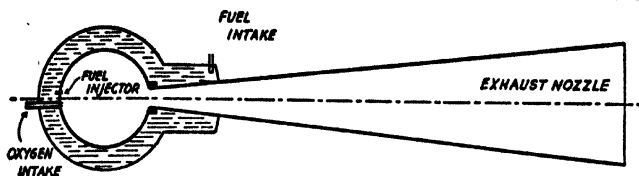
The conclusion, therefore, is that we classify as *jet propulsion any kind of propulsion by reaction where the exhaust jet contains considerable quantities of matter which had not been carried aboard the plane*. Conversely we classify as *rocket propulsion any kind of propulsion by reaction where the exhaust jet consists essentially of matter which had been carried aboard the plane for the purpose of producing such reaction*.

More than ten years went by between Opel's rocket-propelled glider airplane and the first systematic attempt to create a rocket airplane. It was undertaken by an Austrian, Dr. Eugene Sänger, who began his career as a rocket expert with an extensive series of rocket motor tests conducted in the laboratories of the University of Vienna.

These tests were highly successful.

Doctor Sänger's standard model was spherical, with a diameter of about 2 in. The exhaust nozzle was some 10 in. long, with a muzzle diameter equal to the diameter of the spherical combustion chamber. The combustion chamber itself and the part of the exhaust nozzle next to it were surrounded by a cooling liquid jacket. (Fig 46.) The oxygen was fed in directly under high pressure; the fuel was fed into the space between combustion chamber and cooling liquid jacket and thereby served a double purpose: it not only cooled the combustion chamber but also relieved it of the pressure created by the combustion by producing a somewhat higher counterpressure. It was the outer jacket which really took the strain, which it could do all the more easily since it remained cold.

Because of this arrangement Doctor Sänger could follow the practice of the VjR to keep the walls of the combustion chamber thin. The fuel was injected by a Bosch injection pump of the type used in Diesel engines. The



46. Dr. Sänger's Experimental Rocket Motor.

injection pressures were very high, ranging from 30 to about 150 atm. The fuel used was light fuel oil; gaseous oxygen under pressure was frequently substituted for liquid oxygen. The rocket motor itself was suspended in a horizontal position in a framework of steel tubing which could swing horizontally only, pressing against a spring device which measured the thrust.

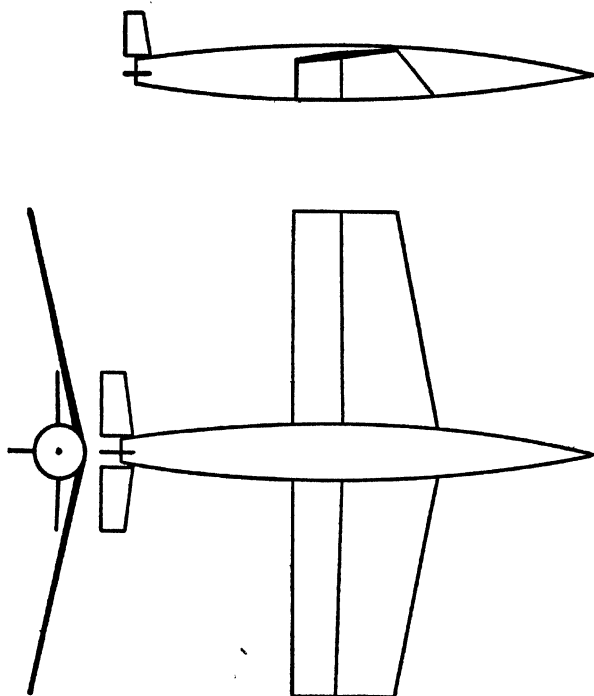
Doctor Sänger achieved astonishingly long burning times. His normal test run lasted 15 minutes, many ran 20 minutes, and one even half an hour. The thrust of the motor was around 55 lb, the exhaust velocity was estimated to have varied between 2000 and 3500 mps (about 6800 to 11,500 fps). But the flame of the exhaust was of the type called "fox tail flame," indicating that the combustion was not quite complete.

These tests convinced him that there was no need to wait for new inventions (like a new alloy) or new discoveries (like a new fuel) to make rocket motors workable and practical, and he set down four conclusions which I'll translate literally:

- (1) The exhaust speed of the combustion gases will become much higher than the main translatoric value for the speed of the gas molecules when the motor is correctly shaped.
- (2) The dissociation which occurs during the combustion does not lead to important losses (of energy) in rocket motors.
- (3) The explosion-like combustion of liquid hydrocarbons in the presence of liquid oxygen occurs with reliable steadiness provided the feed is steady.
- (4) The problem of suitable materials for combustion chamber and exhaust nozzle is most certainly soluble.

The next step was to work out the requirements for the rocket airplane itself. After a long and careful study he arrived at two results, both surprising. One was that a rocket airplane is as much a problem in ballistics as it is in aerodynamics. And the other was that rocket airplanes and ordinary propeller aircraft will never compete with each other.

According to Dr. Sänger propeller airplanes will continue to rule the air for flight speeds of less than 600 mph and for service altitudes of less than 7 miles. Above these limits, where propeller aircraft will hardly be able to function at all, rocket-propelled craft will rule supreme and unchallenged. It is only natural that he also tried to visualize the probable appearance of such a rocket strato-speedster.



47. Dr. Sänger's Sketch of a Stratosphere Rocket Plane.

The fuselage would be long and slender, resembling in shape a heavy naval artillery shell. The cabin would be sealed airtight, of course. The wings would be short and stubby, designed for speeds higher than the velocity of sound in air—so-called “supersonic speeds” of more than 1000 fps or about 780 mph—and set far back on the fuselage in a deep dihedral. The tail assembly would be rather small and grouped around and somewhat in front of the exhaust nozzles. (Fig 47.)

This, of course, is hardly an airplane, but a flying projectile, which can operate efficiently only in the rarefied layers of the stratosphere. The less air resistance it encounters, the higher its efficiency; air resistance, to rocket-propelled craft, is mainly an obstacle and a nuisance.

Naturally the rocket motors are *not* working all the time, the way the engines of ordinary aircraft do; they are to operate only during the ascent. Doctor Sänger advocated a steep climb of about 30 deg. with rocket motor

working until the desired altitude is reached. Then the plane levels off, rocket motors still working. But immediately after leveling the fuel valves are closed, and the craft will then fly with silent engines, slowly losing altitude and speed until it is time to land.

Under these conditions a burning time of 20 minutes would result in a little more than 1 hour of flight with an average speed of 1600 mph. If that performance is compared with reasonable engine-propeller equivalents we find a most interesting result. There is no important difference in fuel consumption. Nor is there an important difference in load-carrying capacity. The use of rocket motors instead of engine-propeller combinations saves only one thing and nothing but that one thing: time. It will be five or five and a half times faster, nothing else.

In a later article, published in vol. 107, No. 2, of the *Schweizerische Bau-Zeitung*, the Journal of the Society of Swiss Architects and Engineers, Doctor Sanger examined the problem of how a rocket motor which can deliver a thrust of 1 ton for 90 sec would change the performance of a pursuit plane.

The assumed gross weight of the plane of his example amounts to 3740 lb and its highest speed in horizontal flight is 320 mph. Such a plane would need 8 minutes to climb to an altitude of 20,000 ft. Equipped with an auxiliary rocket motor furnishing 1 ton of thrust, the same ship would need only 86 sec to climb to 20,000 ft. The climb, assumed to be made at the advantageous angle of 30 deg, would be accomplished by the rocket motor alone, while the propeller would not do more than furnish the power needed to overcome air resistance. The performance may also be expressed by saying that propeller and internal combustion engine would be working normally as if the plane were in horizontal flight at full speed, while the job of lifting the whole is done by the auxiliary rocket device.

That device, of course, occupies some space, but not more than could be made available in such a plane. It consists of three tanks, spherical in shape, one for liquid oxygen, one for compressed nitrogen, and one for fuel oil. These are the bulkiest parts—the outside diameter of the oxygen tank would be about 30 in. while the other two tanks are about equal in size, each having an outside diameter of about 2 ft. The valve assembly and the rocket motor itself are not very bulky; the rocket motor, furthermore, would be put in the extreme tail end where it does not occupy space normally occupied by something else. The weights were calculated by Doctor Sanger as follows:

WEIGHT UNITS	WEIGHT (lb)
Fuel (oil) tank, empty, with valves	22
Oxygen tank, empty, with valves	45
Nitrogen tank, empty, with valves	115
Rocket motor and fuel lines	23
Rocket assembly,	<hr/> 205

(Continued on next page)

ROCKETS

WEIGHT UNITS	WEIGHT (lb)
Fuel (oil)	165
Liquid oxygen	510
Compressed nitrogen	70
Total	<u>950</u>

Being equipped with such an auxiliary rocket, the plane would weigh about 4700 lb instead of 3740 lb, with a resulting increase in take-off speed of about 12 per cent. After the auxiliary rocket has performed its task and carried the plane to 20,000 ft in 90 sec instead of 8 minutes it represents a dead weight of about 200 lb, but it is quite possible that the enormous gain in climbing speed would outweigh the smaller handicap of 200 lb of "useless" weight.

About two years after Hitler had assumed power in Germany, Dr. Sänger left Vienna and joined the Hermann Göring Institute. The purpose of this institute was, of course, aircraft research for the *Luftwaffe* and it was quite obvious that Dr. Sänger had been called because of his work on rocket airplanes. Strangely enough the *Luftwaffe* remained devoid of any indication of Sänger's research activities through most of the war. Even now it is difficult to point to any specific German development and to say, "This is Sänger's work," with the exception of the guided missile *Feuerlilie 25* which was developed by the Hermann Göring Institute for purposes of research.

But there can be no doubt that Dr. Sänger's writings greatly influenced many of the German research engineers who were put to work on rocket-propelled aircraft.

One German rocket airplane was flown operationally as a fighter: the Messerschmitt *Komet* (Me-163B).

Another German rocket-propelled type, an interceptor which had some of the characteristics of a guided missile, had been tested and was about ready for production: the Bachem *Natter* (viper).

A short-range reconnaissance rocket airplane with one rocket unit, the DFS 228, was under development when the Third Reich collapsed, and a scout bomber with two rocket units, the DFS 346, theoretically capable of reaching 100,000 ft altitude and a speed of 1700 mph was in the design stage. This exhausts the list of German rocket aircraft.²

All these planes were designed around a specific rocket motor, labeled the Walter HWK 509.

In general conception and arrangement the Walter rocket motor bore a strong resemblance to the power bay of the A-4 rocket. Its combustion

² Just because it had a human pilot, even though it was designed as a guided missile, the Japanese Baka bomb may be mentioned here. It was a small plane with 16 ft 6 in. wing spread, and about 20 ft long. The nose consisted of a war-head weighing 1200 lb; propulsion was furnished by several large powder rockets. The Baka was carried by a Betty bomber and the two pilots were connected by phone until the pilot of the carrier plane released the Baka with its suicide pilot.

chamber was fuel-cooled, and the two liquids were fed into the motor by two worm gear pumps driven by a small steam turbine. However, the Walter motor operated on different fuels.

The oxidizing agent was not liquid oxygen but an 85 per cent concentration of hydrogen peroxide (H_2O_2) which in such high concentrations has about the same consistency as light syrup. The fuel was a 30 per cent solution of hydrazine hydrate ($\text{N}_2\text{H}_4 \cdot \text{H}_2\text{O}$) in methyl alcohol. The purpose of the hydrazine hydrate was to make ignition devices unnecessary since it ignites spontaneously when coming in contact with hydrogen peroxide.

The steam generator for the turbine which drove the pumps was fed with hydrogen peroxide by a small by-pass line. The porcelain-lined pressure container which formed the steam generator was equipped with a wire screen holding pellets of calcium or potassium permanganate. The pilot could control the whole by a single throttle lever which could be set for "off," for "idling," and for three power stages. There also was an automatic cut-off valve which was operated by excess pressure in the combustion chamber.

The latter was made of steel and was cylindrical with slightly rounded ends. Its length was 11 in. and its internal diameter $9\frac{1}{2}$ in. The cooling jacket was also made of steel. The circulating liquid was, of course, the hydrazine hydrate-methyl alcohol solution, not the hydrogen peroxide.

The whole Walter motor weighed about 365 lb and it developed a maximum thrust of 3300 lb at sea level, 3650 lb at 40,000 ft. Fuel consumption for this thrust was just above 8 kg per second or 17.75 lb. This corresponds to an exhaust velocity of 1875 mps which is almost precisely half of the theoretical exhaust velocity. By throttling the Walter motor down to one system of fuel lines only it could be made to give a thrust as low as 220 lb (100 kg), but it was found to operate inefficiently when throttled to such an extent. For this reason a certain modification was built for use in the Messerschmitt Me-163 which will be discussed later. In the *Natter* (viper) it was used without this modification.

This *Natter* has been described in the official British Air Ministry report on German aircraft as a "last ditch attempt" to stop the heavy Allied bombing raids. It was a kind of airplane consisting mostly of a massed battery of twenty-four 73-mm projectile rockets in the nose and of a Walter rocket unit in the tail. It had very short and stubby wings, with an area of only 1250 sq ft, and took off *vertically* from a launching rack. For this take-off the Walter rocket unit was assisted by two powder rockets, each capable of delivering 1000 lb thrust for 12 sec.

Initial rate of climb of the *Natter* was more than 37,000 fpm and the speed at 18,000 ft was over 600 mph. During the ascent the pilot was inactive. His duty was to direct the *Natter* against Allied bomber formations once the necessary altitude had been attained. After firing his 24-rocket salvo the pilot was to press a button which operated his "ejector seat" which flung him free of the plane. The *Natter* itself broke apart immediately afterwards, but the tail

end with the Walter motor was equipped with a separate parachute so that the motor could be salvaged for re-use.

The *Natter* (or, to give the full designation, Bachem BP 20) was not actually used in combat but did progress to the state of test flight.

The other German rocket airplane, the Messerschmitt *Komet*, was encountered by Allied airmen for the first time on August 16, 1944, over Leipzig. One of the best early descriptions was given by Lt. Col. John Murphy of Tulsa, Oklahoma, who commanded a squadron of Mustang fighters escorting the bomber force which consisted of Flying Fortresses. He tried to catch one of these planes which was driving for a B-17 Fortress, but was unable to do so because the Messerschmitt "got there in one easy sweep, while I was grinding out all the speed I could." A little later, however, the same officer caught one of the Messerschmitts at 23,000 ft. The German was much faster than the Mustang, but because of that the Mustang was more maneuverable and forced the German into a dive for safety. Following down to 10,000 ft, the Mustang succeeded in getting in a prolonged burst of gunfire which caused the Messerschmitt to blow up.

Blow-ups of German *Komet* fighters in midair have been reported repeatedly by Allied airmen, even when the planes were not attacked at all. It was probably a result of spontaneous decomposition of the hydrogen peroxide in the tanks which on occasion reverts to water and oxygen³ with explosive suddenness. This decomposition is caused by the catalytic action of some heavy metals which need to be present only in very small traces. While anti-catalysts are known they are not reliable, and hydrogen peroxide cannot be considered safe as an oxygen carrier for rocket motors.

Those old members of the *Rhön-Rossitten Gesellschaft* who were still around to see the Me-163 in action may have been struck by the similarity of that rocket-propelled fighter to the 6-foot model *Storch* which they had helped to test in 1928. That resemblance was not accidental; the Me-163 had among its designers one whose name was A. Lippisch.

Since the Messerschmitt *Komet* was the first rocket airplane to be flown operationally, its description in the British Air Ministry report may be quoted in full:

³ The decomposition follows the equation $2\text{H}_2\text{O}_2 = 2\text{H}_2\text{O} + \text{O}_2$. While hydrogen peroxide contains 94.2 per cent of oxygen by weight, only 47.2 per cent of oxygen is available for combustion. However, the decomposition itself supplies 1323 cal. per gram so that the effectiveness of hydrogen peroxide is higher than indicated by the figure of 47.2 per cent of available oxygen.

APPENDIX I

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MESSERSCHMITT ⁴

Me 163 B

DEVELOPMENT	Developed from Me 163 A, an earlier training version.
SUB-TYPES	Common operational sub-type is Me 163 B-1.
DUTIES	Interceptor. (The aircraft was developed for the defense of specific targets.)
WINGS	Of special swept-back design with a marked wash-out of incidence towards the tip. Wooden construction with an 8 mm plywood skin covered with doped fabric. The built-up main spar is of laminated wood and is 13 ins. deep at the root. A leading edge slot over 7 ft. long terminates about 12 ins. from the wing tip. The "elevons" which serve the dual function of elevators and ailerons, are mounted outboard and are of composite construction. Inboard of the "elevons" are large fabric-covered trimming surfaces operated by a screw jack. Simple split flaps are fitted in the under surface of each mainplane forward of the trimming surfaces.
FUSELAGE	The fuselage is of metal construction and is made in two halves. The rear portion containing the rocket unit is detachable.
TAIL UNIT	There are no horizontal surfaces; only the vertical fin and rudder. The rudder is aerodynamically balanced and has a plate tab.
UNDERCARRIAGE	The aircraft normally takes off under its own power on a jettisonable twin-wheel undercarriage. At the time of take-off, the retractable landing skid is extended; when the skid is retracted the wheels are automatically dropped. A castoring tail wheel is faired into the lower portion of the fin.
POWER PLANT	The Walter 109.509 bi-fuel liquid rocket unit is just over 7 ft. long and is supplied ready for mounting. There are two main assemblies. The forward consists of a housing for the turbine; two worm type pumps for delivering the fuel, a control unit; pressure-reducing valve; and an electric starter motor. A small cylindrical unit is attached to the forward housing; this produces steam to drive the turbine, by the action of a solid catalyst on the hydrogen peroxide (T-Stoff). The second assembly consists of the combustion chamber unit.

⁴ Official Report on German Aircraft, compiled by the British Air Ministry and released, Sept. 12, 1945, by Public Relations Office, Air Technical Service Command, Wright Field, Dayton, Ohio, pp. 77, 78.

ROCKETS

POWER PLANT	The fuels are T-Stoff (concentrated hydrogen peroxide) and C-Stoff (a solution of hydrazine hydrate in methanol). The T-Stoff tanks hold about 226 gallons, and the C-Stoff tanks 110 gallons.
ACCOMMODATION	A mechanical jettisonable hinged plexiglas moulding forms the cockpit cover. The main instrument panel is hinged to give access to the equipment housed in the armour nose conc. The pilot's seat is of conventional design.
ARMAMENT	Two MK 108 30 mm guns are normally fitted, one in each wing root. The ammunition, 60 rounds per gun, is carried in 2 boxes under a detachable fairing in the fuselage.
DIMENSIONS	Span 30.6 ft. Length 19.4 ft. Net wing area 186 sq. ft.
WEIGHTS	The normal flying weight is approx. 9,500 lb.
PERFORMANCE	The top speed is about 550 m.p.h. at 20,000 ft. and above, and the climb to 30,000 ft. takes 2.6 min.

Me 163 C

The Me 163 C was developed from the Me 163 B and is slightly larger, the principal dimensions being: Span 32.2 ft., length 23.1 ft., net wing area 197 sq. ft. It has a Walter 109.509 C rocket unit with an auxiliary cruising jet, smaller than the main jet, positioned immediately below it in the tail. Thus the total thrust is 3,740 plus 660 lbs. The endurance is 12 min. and the maximum speed 590 m.p.h. between 13,100 ft. and 39,300 ft. The ceiling is 52,500 ft. and a pressure cabin is fitted. The take-off weight is 11,280 lbs.

The cockpit canopy is the "bubble" type, and the step in the forward belly which houses the retractable landing skid is not so pronounced as on the 163 B. The armament is two MK 108's mounted in the nose of the fuselage above the center line.

There exist American equivalents to the Walter rocket motor. Late in 1945 visitors to Wright Field were shown two rocket units developed for the Army Air Force by Aerojet Engineering Corporation in Pasadena, California. These planes, designated XCALT-6000 and X40ALD-3000, were capable of developing 6000 and 3000 lb of thrust, respectively. These units operate on red fuming nitric acid (HNO_3) as an oxygen carrier and on aniline ($\text{C}_6\text{H}_5\text{NH}_2$) as a fuel; like the T-Stoff C-Stoff combination, this mixture is spontaneously combustible.

Aerojet-developed rocket units also played a role in the other application where rocket propulsion and aviation come together. This is what came to be called *Jato*, compounded from *jet-assisted take-off*.

The idea of using rocket power to assist in the take-off of airplanes originated soon after the First World War. At first its application was considered only

where it was needed most: for pontoon-equipped seaplanes. In about 1921 somebody suggested jetting a stream of water from the pontoons to get a seaplane into the air. Then aviation engineers began to wonder about a more general application of this principle, on the theory that any plane needs more power for the take-off than in flight. The idea was to save the extra engine power and gasoline consumption by equipping planes with only as much engine power as was needed for cruising and providing the extra power needed for the take-off by rockets.

Professor Hugo Junkers, then still alive, tested at least part of that idea by taking a single-engined Junkers plane with floats—the same type which made one of the first transatlantic flights—and fitting it with a battery of powder rockets. He overloaded it to such an extent that it could not conventionally take off anymore. Just how much it was overloaded was not stated, but the normal take-off weight of these planes was around 3 tons. At any event, the take-off of the overloaded plane with the aid of the battery of rockets was successful.

This experiment had been made in great secrecy in August 1929, and nothing was heard of it again until it found practical application during the Battle of Britain. The *Luftwaffe* then launched overloaded bombers from small improvised airdomes in Holland and Belgium. The bombers had a kind of metal grating fitting the bottom of the fuselage and carrying the rockets, which were ignited electrically by the pilot when the engine was running with full power. When the rockets were exhausted, the grating dropped off the plane, which by then was in the air.

Later in the war our Navy became interested in such take-off help for two reasons. One was simply to shorten the take-off run of flying boats which often are difficult to lift off the water, especially when overloaded. The other was that if rocket help would cut in half or less the length of a normal take-off run it would be possible to launch from the flight decks of carriers airplanes that normally could not operate from such a restricted area.

The device that was finally developed looked very much like a bomb. Two or four of them were attached to the wings of the planes near the fuselage. Many spectacular exploits, especially in the Pacific, would have been impossible without this device.

The discussion of efficiency earlier in this chapter may lead some readers to ask why the rockets work efficiently for this purpose. The answer is that they don't. Rocket efficiency as take-off help is decidedly poor. But in this case that poor efficiency is acceptable because it accomplishes something which could hardly be accomplished in any other way. If you have the choice between getting heavy planes off a carrier's flight deck with poor efficiency or of not getting them off at all, there is little doubt as to what will be preferred. In commercial flying this principle might be useful in getting large transports off short runways. Whether there will be any economic advantage in doing so is somewhat doubtful at this moment. But the rocket unit for take-off help might become a piece of standard equipment for use in emergency.

Appendix 2:

NOTES AND TABLES

ADDENDUM TO CHAPTER 3.

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Written in the form of an equation, the Third Law of Motion reads $MV = mv$, where M and m are the masses involved and V and v the velocities. It is customary, however, to use v for the velocity of the rocket and c for the velocity of the exhaust. Likewise it has become customary to refer to the mass of the rocket before working (burning) as M_0 and to the mass of the rocket afterwards as M_1 .

The differential equation governing rocket motion is

$$m \times dv + c \times dm = 0.$$

The most important relationship which can be derived from this formula is the expression for the velocity v which states that v equals c multiplied by the "natural logarithm" of the mass-ratio M_0/M_1 . Natural logarithms are those which are based on e which equals 2.71828183..., the result of the series $1 + 1/1! + 1/2! + 1/3! + 1/4! + \dots$

Using the factor e , the mass-ratio can be expressed in a very simple manner as $e^{v/c}$. This factor, multiplied with the remaining mass of a rocket, permits establishing its take-off mass without difficulties. Of course v (velocity) and c (exhaust velocity) have to be known. A table which permits the finding of the proper value for the mass-ratio will follow at the end of this "note," and several examples of the use of this factor will be discussed in the "Note on Rocket Artillery."

But it is also possible to arrive at e in an elementary manner, by calculating the remaining mass for several assumed rockets, ejecting definite proportions (like halves, quarters, hundredths, etc.) of their mass. An example of this has already been given in Fig. 10, p. 67. Carrying the same method further, one may obtain a number of results that can be tabulated in the following manner:

$v = c$ when the mass-ratio equals	4	(expelling halves)
	3.375	" thirds
	3.165	" quarters
	2.868	" tenths
	2.729	" hundredths
	2.723	" thousandths
	2.720	" ten thousandths

When "infinitely small" parts are expelled the ratio drops to 2.7182... which is e . This case holds true for actual rockets of any type, powder or liquid

fuel, since gas molecules may be considered as infinitely small as compared to the size of the rocket.

The following table, worked out by Professor Oberth, permits instant finding of the proper mass-ratio within wide limits.

	$v =$	500	1,000	2,000	3,000	4,000	5,000 m/sec.
$c =$	1.000	1.64	2.72	7.39	20.0	54.5	148
m/sec.	2.000	1.29	1.64	2.72	4.48	7.39	12.2
	3.000	1.18	1.39	1.94	2.72	3.78	5.29
	4.000	1.13	1.29	1.64	2.11	2.72	3.49
	5.000	1.10	1.22	1.49	1.82	2.22	2.72
	$v =$	6,000	7,000	8,000	9,000	10,000	11,000 m/sec.
$c =$	1.000	405	1089	2987	8060	22,070	60,000
m/sec.	2.000	20.0	33.0	54.5	89.6	148.7	243.5
	3.000	7.39	10.25	14.35	20.0	27.95	39.0
	4.000	4.48	5.76	7.39	9.5	12.20	15.75
	5.000	3.32	4.06	4.95	6.06	7.39	9.02
	$v =$	12,000	13,000	14,000	15,000	m/sec.	
$c =$	1.000	163,100	444,000	1,200,000	3,290,000		
m/sec.	2.000	402	662	1,091	1,805		
	3.000	54.6	76.1	106.3	148.7		
	4.000	20.0	25.8	33.2	42.7		
	5.000	11.0	13.47	16.42	20.0		

From Die Möglichkeit der Weltraumfahrt.

Note on Rocket Artillery

A comparison between some known gun performances and rocket performances on the basis of the mass-ratio concept leads to very interesting results. This comparison can be made in a simplified manner by substituting the highest rocket velocity v for the muzzle velocity of the gun used for comparison. The value of c for the following examples has been assumed to be 1 mps; which may be expected to be approximately correct for the modern cordite rocket powders.

Luckily there are two extremes of known gun performances where the weight of the projectile fired was virtually the same in both cases, the German Paris Gun of 1918 with an 80-mile range and the French 220-mm. mortar of 1887 with a minimum range of only 600 meters. In both the shells weighed 260 lb., so in our hypothetical rockets, used for comparison, the value of M_p ("pay load") is the same all the way through.

The Paris Gun, firing with a muzzle velocity of almost precisely 1 mps. and with 56 deg. elevation attained a maximum range of 82 miles, with a peak

elevation of the trajectory of 30 miles—the longest range and the highest trajectory peak before V-2. The mass-ratio for a rocket supposed to attain equal velocity would be just $e = 2.72$. Since the empty shell M_R of such a rocket could hardly weigh less than 240 lb., the remaining mass M_1 (equal to $M_R + M_F$) would be 500 lb. Multiplying this by e we obtain 1360 lb. for M_0 or a weight of 860 lbs. for the fuel charge M_F . The propelling charge of the Paris Gun weighed 650 lb.

At the other end of the scale of artillery ranges we have the French 220-mm mortar Model 1887 which fired with an elevation of about 66 deg. and attained ranges varying from 600 to 3200 m/sec. The muzzle velocity for minimum range was 90 mps., the weight of the propelling charge 2.5 lb. For maximum range the muzzle velocity was 230 mps., the propelling charge 13.5 lb. If the rocket carrying such a projectile is assumed to have a dead weight of 25 lb., M_1 becomes 285 lb. For maximum range the take-off weight would be about 328 lb., for minimum range about 310 lb.; in each case the fuel charge would be considerably heavier than the propelling charge for the gun.

All three examples, Paris Gun and French 220-mm. mortar for maximum and minimum range, calculated for an exhaust velocity of 1000 yps. (compressed blackpowder mixtures), would result in the following take-off weights: 3000, 400, and 330 lb., respectively. It becomes obvious that the "waste" of propelling charge, as compared to the propelling charge in a gun, decreases as the exhaust velocity of the rocket charge increases. It can also be seen that the difference between the two types of propelling charges becomes less as the range increases. In a 150-mile shot both, gun and rocket, might become equal in this respect.

Although these examples point once more to the desirability of high exhaust velocities even for earthbound projectile-carrying rockets, there is a limiting value where a further increase in exhaust velocity has any value to the designing engineer. Assuming that atomic energy can be utilized in accelerating the exhaust of V-2 type long-distance bombardment rockets, we'll examine two sets of examples, for a range of 400 km. (250 miles) and 1000 km. (600 miles) with exhaust velocities ranging from 2000 to 20,000 mps.

1000-kilometer (600-mile) shot, elevation 45°

$v = 3160$ mps. (approx. 8400 fps.)

c (in mps.)	MASS-RATIO
	M_0/M_1
2000	4.51
3000	2.72
4000	2.11
5000	1.82
10,000	1.36
20,000	1.15

400-kilometer (250-mile) shot, elevation 45°

$v = 2000$ mps. (approx. 6550 fps.)

c (in mps.)	MASS-RATIO
	M_0/M_1
2000	2.72
3000	1.94
4000	1.64
5000	1.49
10,000	1.22
20,000	1.10

While, naturally, every increase in exhaust velocity corresponds to a decrease in mass-ratio, there is a certain point where that decrease is no longer important. It would present no difficulty to construct a mass-ratio of 1.6:1. If that can be done a mass-ratio smaller than, say, 1.6:1 would not represent a very great advantage from the point of view of the designer any more, while the increase in exhaust velocity required to drop the mass-ratio by another 10 per cent may represent considerable difficulties.

In other words, from the practical point of view there exists a convenient mass-ratio which does not need to be reduced any more, or where further reduction is practical only if higher exhaust velocities can be achieved without even minor difficulties. That condition naturally varies with the required range and the value for v ; generally speaking it will be obtained when $c = 2v$.

ADDENDUM TO CHAPTER 4

Since the numerous patents of Professor Goddard form his major contribution to rocket literature, I here append a list of them (which I believe to be complete) in chronological order:

- No. 1,102,653, July 7, 1914 "Rocket Apparatus"
- No. 1,103,503, July 14, 1914 "Rocket Apparatus"
- No. 1,191,299, July 18, 1916 "Rocket Apparatus"
- No. 1,194,496, August 15, 1916 "Rocket Apparatus"
- No. 1,206,837, December 5, 1916 "Rocket Apparatus"
- No. 1,341,053, May 25, 1920 "Magazine Rocket"
- No. 1,809,271, June 9, 1931 "Propulsion of Aircraft"
- No. 1,834,149, December 1, 1931 "Means for Decelerating Aircraft"
- No. 1,879,187, September 27, 1932 "Mechanism for Directing Flight"
- No. 1,980,266, November 13, 1934 "Propulsion Apparatus"
- No. 2,016,921, October 8, 1935 "Means for Cooling Combustion Chambers"
- No. 2,026,885, January 7, 1936 "Aircraft"
- No. 2,090,039, August 17, 1937 "Igniter"
- No. 2,122,521, July 5, 1938 "Cooling Jacket Construction"
- No. 2,158,180, May 16, 1939 "Gyroscopic Steering Apparatus"
- No. 2,183,311, December 12, 1939 "Means for Steering Aircraft"

- No. 2,183,312, December 12, 1939 "Fuel Storage & Discharge Apparatus"
 No. 2,183,313, December 12, 1939 "Combustion Chamber for Aircraft"
 No. 2,183,314, December 12, 1939 "Gyroscopic Apparatus for Directing Flight"
 No. 2,217,649, October 8, 1940 "Combustion Chamber for Rocket Apparatus"
 No. 2,271,224, January 27, 1942 "Parachute Attachment for Aircraft"
 No. 2,286,908, June 16, 1942 "Auxiliary Turbine for Rocket Craft"
 No. 2,286,909, June 16, 1942 "Combustion Chamber"
 No. 2,307,125, January 5, 1943 "Launching Apparatus for Rocket Craft"

Note on Rocket Motor Efficiency

Most of the formulae which can be found in literature and which are supposed to be useful for determining the efficiency of a rocket motor are simply wrong because they were designed to avoid the "impossibility" of obtaining efficiencies above 100 per cent if v becomes greater than c . The correct procedure is to distinguish between inner or thermal efficiency and outer or ballistic efficiency. For the latter Dr. Sänger evolved the formula

$$E_{\text{ball.}} = \frac{2 cv}{c^2 + v^2}$$

which is the factor with which the thermal efficiency has to be multiplied.

Note on Other Rocket Societies

In the wake of the founding of the VfR a number of other rocket societies were founded. The Russian society, under Rynin, Dr. Perelman, and others, was called *GIRD*, a name formed from the initials of the Russian words for "Group for the Study of Reactive Motion." The Moscow branch and the Leningrad branch were known as the *Mosgird* and *Lengird*, respectively.

In Austria Dr. von Hoefft had originally founded the *Oesterreichische Gesellschaft für Höhenforschung* (Austrian Society for High-Altitude Exploration) which was later superseded by the *Oesterreichische Gesellschaft für Raketentechnik* (Austrian Society for Rocket Technology) founded by von Pirquet and Zwerina.

In Great Britain the British Interplanetary Society was founded in 1933 by P. E. Cleator in Liverpool. It was later transferred to London. Other similar societies were founded elsewhere in Great Britain. They all officially suspended operations for the duration of the Second World War and have now been united into one society.

In the U. S. A. several societies existed at one time or another; one of them was the "Cleveland Rocket Society" under Ernest Loebell which ceased to exist in 1937. A proving ground had been established but was used only for very few experiments. At present there are only two in existence, the oldest and the youngest of them. The latter is the U. S. Rocket Society, founded by R. L. Farnsworth, Jr., in Glen Ellyn, Illinois. It is active mostly in a literary manner; like the British Society (and unlike the American Rocket Society) it is expressly devoted to the idea of space travel.

Oldest of the American societies is the American Rocket Society in New York, which was founded in March 1930 by G. Edward Pendray and David Lasser under the name of the American Interplanetary Society. This society is the only one in this country which actually built a rocket, or rather several. The first was a two-stick repulsor patterned frankly after the V/R model. It was damaged during its first test run in autumn 1932. Most of its parts, especially the tanks and the motor, could be salvaged, and the new rocket, called "No. 2," was tested at Marine Park, Great Kills, Staten Island, in May 1933. The society's journal, *Astronautics* (No. 26.), reported on the test as follows:

Experimental Rocket No. 2 of the American Interplanetary Society was shot at twenty minutes past eleven o'clock, Sunday, May 14. It reached an altitude of approximately 250 feet after firing a trifle more than two seconds. At that height the flight was brought to an abrupt end by the bursting of the oxygen tank.

After this three more rockets, called No. 3, 4, and 5, were planned. No. 5 turned out to be hopeless nonsense; No. 3 was built but could not be fueled and was therefore useless. No. 4, a one-stick repulsor, was tested September 9, 1934. It took off with high acceleration and rose almost vertically to about 300 ft. At that point one of the four nozzles of the motor burned out and the rocket assumed a strange weaving motion. The peak altitude is estimated to have been 382 ft. It covered a horizontal distance of 1300-1400 ft. The rocket struck the water with great violence and was so badly smashed that it could not be repaired. The newly devised parachute release had no chance to function.

Since that experiment only ground tests have been performed. The record is a 12-sec. run on June 22, 1941, when a ceramic-lined motor designed by Alfred Africano produced a recoil of more than 260 lb. for about 2 sec. Lack of a permanent workshop and proving ground, combined with an almost frantic desire to avoid "conventional methods," resulted in a rather erratic program and may explain the comparatively small amount of work done between 1935 and the outbreak of the Second World War.

Many of the leading members of the American Rocket Society, which at one time loudly began to reject any "accusation" of striving for the conquest of interplanetary space and became intensely "practical" and "down to earth," seem to have joined the staff of a firm called "Reaction Motors, Inc." That firm was founded in 1939 or 1940 and has been doing rocket research work for the U. S. Government. Most of this work may have to remain secret, but some of it has been described by G. Edward Pendray in his book *The Coming Age of Rocket Power* (See Bibliography).

Note on Rocket Mail

In 1931 it became known that an Austrian engineer by the name of Friedrich Schmiedl was operating a rocket mail route in Styria, mostly between Schöckel and Radegund, which had some kind of semi-official status. Schmiedl used 6-ft. powder rockets of his own manufacture which ejected the mailbag (equipped with parachute) shortly before crashing, roughly halfway down

the descent. Extensive correspondence taught me that Schmiedl was on his way to make rocket mail for certain purposes and under certain conditions practical. He was mainly thinking of mountainous territory where two villages might be separated by only a few miles, but still a day's walk apart. Such mail shooting might also be practical for islands fringed by a heavy surf (I have read somewhere that mail was carried by heavy naval signal rockets to some islands in the South Seas over 20 years ago), where a mail steamer travels for many hours within sight of a coast before actually making port. A list of Schmiedl's mail shots, compiled by the experimenter himself in 1933, reads as follows. (V stands for *Versuchsrakete*, meaning experimental rocket; beginning with R-1 the mail was received officially by the local post offices.)

DATE	ROCKET	FROM	TO	LETTERS TRANSPORTED	
				TOTAL	REGISTERED
Feb. 2, 31	V-7	Schöckel	Radegund	102	—
Apr. 21, 31	—	"Kalte Rinne"		79	—
Oct. 28, 31	V-8	Grazer Feld		84	(night test)
Sept. 9, 31	R-1	Hochtrötsch	Semriach	333	36
May 28, 32	V-9	Schöckel	Radegund	228	125
same	V-10	Schöckel	Radegund	192	113
June 11, 32	V-11	Grazer Feld		28	(storm test)
July 23, 32	V-12	Schöckel	Kumberg	231	187
same	V-13	Schöckel	Kumberg	200	100
March 16, 33	V-14	Garrach	Arzberg	283	—

After the highly successful tests of 1932 Schmiedl was trying to establish a regular schedule, but the Schuschnigg government suddenly forced him to destroy all of his work, including the launching ramp at Schöckel (Styria). No reason or explanation was given, but dealing with Schuschnigg's government was hardly less dangerous than taunting the *Gestapo*, so Schmiedl had to consent to destroy his own work.

The German experimenter Gerhard Zucker tried to get into the good graces of the Hitler government by making similar mail shots for the Winter Help. He then went to England where he tried unsuccessfully to demonstrate his mail rockets. Zucker's mail rockets were exceedingly simple in design: a centrally located steel tube served as container for the powder rocket, the mail was put into the compartments formed by an outer jacket. Soon after Zucker's return to Germany his death was announced. He is said to have been executed in a concentration camp near Hamburg.

Several other attempts along these lines were made in various countries and one of them, an experimental rocket mail test near Havana, has been recognized by an official Cuban airmail stamp, issued by the Cuban Postmaster General in 1939 and bearing the inscription *Experimento del Cohete Postal, Año de 1939* (Scott's Catalogue No. C25). All other so-called rocket mail stamps, including Schmiedl's, are not official.

HUMPHREY'S TABLE ON THE VARIATION OF TEMPERATURE, PRESSURE
AND DENSITY WITH ALTITUDE.

(Compiled from actual records obtained by sounding balloons in flights made
near Paris, Brussels, Munich, and Strassburg.)

760 mm Hg = 29.921 inches = 1,013.3 millibars.

altitude km	C°	mm Hg	density of dry air in gram/cm ³
20.0	-51 (-57)*	44.1 (39.5)	0.000092 (0.000085)
19.0	-51 (-57)	51.5 (46.3)	0.000108 (0.000100)
18.0	-51 (-57)	60.0 (54.2)	0.000126 (0.000117)
17.0	-51 (-57)	70.0 (63.5)	0.000146 (0.000137)
16.0	-51 (-57)	81.7 (74.0)	0.000171 (0.000160)
15.0	-51 (-57)	95.3 (87.1)	0.000199 (0.000187)
14.0	-51 (-57)	111.1 (102.1)	0.000232 (0.000220)
13.0	-51 (-57)	129.6 (119.5)	0.000270 (0.000257)
12.0	-51 (-57)	151.2 (140.0)	0.000316 (0.000301)
11.0	-49.5 (-57)	176.2 (164.0)	0.000366 (0.000353)
10.0	-45.5 (-54.5)	205.1 (192.0)	0.000419 (0.000408)
9.0	-37.8 (-49.5)	237.8 (224.1)	0.000470 (0.000466)
8.0	-29.7 (-43.0)	274.3 (260.6)	0.000524 (0.000526)
7.0	-22.1 (-35.4)	314.9 (301.6)	0.000583 (0.000590)
6.0	-15.1 (-28.1)	360.2 (347.5)	0.000649 (0.000659)
5.0	- 8.9 (-21.2)	410.6 (398.7)	0.000722 (0.000735)
4.0	- 3.0 (-15.0)	466.6 (455.9)	0.000803 (0.000821)
3.0	+ 2.4 (- 9.3)	528.9 (519.7)	0.000892 (0.000915)
2.5	+ 5.0 (- 6.7)	562.5 (554.3)	0.000942 (0.000967)
2.0	+ 7.5 (- 4.7)	598.0 (590.8)	0.000990 (0.001023)
1.5	+10.0 (- 3.0)	635.4 (629.6)	0.001043 (0.001083)
1.0	+12.0 (- 1.3)	674.8 (670.6)	0.001100 (0.001146)
0.5	+14.5 (- 0.0)	716.3 (714.0)	0.001157 (0.001215)
0.0	+15.7 (+ 0.7)	760.0 (760.0)	0.001223 (0.001290)

* The figures in parentheses refer to winter conditions.

ADDENDUM TO CHAPTER 7.

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Note about Altitudes Attained by Radiosondes

Meteorological data obtained by radiosondes are published every month by the U. S. Weather Bureau in its *Monthly Weather Review*. Because both the editors and the readers of this publication are primarily interested in the meteorological data rather than in the means used to obtain them, the published tables list airplane flights and radiosonde flights together. But since it may be safely assumed that the airplane flights of the pre-war period were not likely to go to altitudes beyond 10 km (not quite 33,000 ft) it is possible

to form an idea of the average performance of radiosondes by using only the figures referring to altitudes from 10 km upwards.

From the September 1941 issue of the *Monthly Weather Review* (it bears that date because it contains the results obtained in that month, without regard to the actual date of publication), listings of the number of ascents from six weather stations were selected. Three of these stations are virtually at sea level, the other three are situated at increasing altitudes. As the following table shows, the altitude at which a station is situated does not seem to have much influence on the altitudes obtained by the radiosondes; the two columns referring to Nome, Alaska (which is 45 ft above sea level) and to Buffalo, N. Y., about 700 ft above sea level, look almost alike. So do the columns for 60-ft-high San Diego, Calif. and mile-high Denver, Colo.

An analysis of the figures shows that half of the radiosondes which reach the 10-km level will attain 18 km which is just short of 60,000 ft. But only 8 per cent of those that rose to 10 km will go to 20 km, indicating that meteorological rockets would have virtually no competition from 60,000 ft up.

NUMBER OF RADIOSONDES WHICH REACHED SPECIFIED ALTITUDES IN ROUTINE FLIGHTS FROM SIX U. S. WEATHER STATIONS DURING THE MONTH OF SEPTEMBER 1941

ALTITUDE REACHED	WEATHER STATION						TOTAL
	San Diego, Calif.	Nome, Alaska	Pearl Harbor, Hawaii	Buffalo, N. Y.	Atlanta, Ga.	Denver, Col.	
(km)	(19 m)	(14 m)	(7 m)	(221 m)	(300 m)	(1616 m)	
10	21	25	20	26	28	25	145
11	19	25	19	26	28	20	137
12	17	23	18	23	28	19	128
13	13	22	16	22	27	17	117
14	11	21	14	21	26	16	109
15	9	20	10	20	26	16	101
16	7	20	8	19	26	15	95
17	6	18	6	17	24	14	85
18	6	14	5	15	23	8	71
19	—	11	—	10	12	—	33
20	—	5	—	6	—	—	11

These figures can be summed up as follows:

- to 10 km 145 radiosondes, called 100 per cent
- to 15 km 101 radiosondes, or 70 per cent of the first figure
- to 18 km 71 radiosondes, or 49 per cent of the first figure
- to 20 km 11 radiosondes, or 8 per cent of the first figure

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Method of Calculation of Rocket Ascents

It was assumed that the thrust P is constant. The air resistance F was calculated as $338 \times R^3 \times i \times \gamma \times f(v)$ (as given by Siacci in Cranz-Becker: *Ballistics*). For the air density (γ) the Hohmann formula was used. (See table at the end of this note.) The factor i was assumed to be 1.2, much higher than for artillery projectiles where it only equals 0.865.

The formulae used follow:

Ascent under power:

$$\text{Acceleration } a = \frac{(P - W - D)}{W} \times g.$$

$$\text{Speed } v_2 = v_1 + \frac{(P - W - D)}{W} g \times \Delta t$$

$$\text{Altitude } s_2 = s_1 + \frac{v_1 + v_2}{2} \times \Delta t$$

Free Ascent:

$$v_2 = \sqrt{v_1^2 - \frac{2g}{W_1}(h_2 - h_1) \times (D + W_1)}$$

Explanation of symbols:

D in kilograms	Air resistance.
R in meters	Radius of rocket.
$i = 1.2$	
γ in kg/m ³	Density of the air.
$f(v)$	According to Siacci (Cranz-Becker: <i>Ballistics</i>).
a in m/sec ²	Acceleration.
a_0 in m/sec ²	Effective acceleration at beginning of ascent.
v in m/sec	Speed of rocket at any given moment.
s in meters	Altitude attained under power.
h in meters	Altitude attained "free."
$H = s + h$	Total altitude.
P in kilograms	Thrust.
W in kilograms	Weight of rocket at any given moment.
W_0 in kilograms	"Take-off weight" of rocket.
W_1 in kilograms	Weight empty, but including instruments.
t in seconds	Time.
g	Assumed to be the same at any altitude attained by rocket with the value of 9.81 m/sec ² .

The computation of the ascent under power was made with intervals of $\Delta t = 2$ seconds. For this interval W , γ and $f(v)$ were assumed to be constant with the value which is correct for the first instant of this interval. The error thus created is very small and has the tendency to cancel out during the computation. The free ascent was calculated with intervals (of altitude) of $(h_2 - h_1) = 500$ meters. The variables were treated in the same manner.

ROCKETS

The results of these rather tedious computations are condensed in the following two tables:

TABLE I

$W_0 = 20$ kg; $W_1 = 10$ kg; $W_F = 10$ kg; $R = .05$ m.

The symbols are the same as those used in the formulae, with the following additions:

W_F —Weight of fuel and liquid oxygen

W_1 —Fuel (and oxygen) consumption per second

v_{max} —Highest velocity attained by the rocket during the ascent

T —Time required for complete consumption of fuel and oxygen.

	c (m/sec)	a_s (m/sec ²)	P (kg)	W_1 (kg/sec)	T (sec)	v_{max} (m/sec)	s (km)	h (km)	$H=s+h$ (km)
1.	2000	1 g	40	.196	51.0	460	12.9	7.2	20.1
2.	2000	2 g	60	.294	34.0	515	10.2	7.1	17.3
3.	2000	4 g	100	.491	20.4	590	7.2	7.0	14.2
4.	2500	1 g	40	.157	63.7	575	18.7	12.2	30.9
5.	2500	2 g	60	.236	42.5	625	14.7	11.3	26.0
6.	2500	4 g	100	.392	25.5	695	10.3	10.3	20.6

TABLE Ia

Case No. 5 under the assumption that the rocket is fired from the top of a high mountain instead of sea level.

Height of mountain assumed to be 4 km in case No. 5a

5 km in case No. 5b

5a	2500	2 g	60	.236	42.5	790	20.8	22.6	43.4
5b	2500	2 g	60	.236	42.5	830	22.3	26.4	48.7

TABLE II

$W_0 = 46$ kg; $W_1 = 26$ kg; $W_F = 20$ kg; $R = .06$ m.

	c (m/sec)	a_s (m/sec ²)	P (kg)	W_1 (kg/sec)	T (sec)	v_{max} (m/sec)	s (km)	h (km)	$H=s+h$ (km)
1.	2000	1 g	92	.451	44.4	465	10.8	7.8	18.6
2.	2000	2 g	138	.676	29.6	545	8.8	9.1	17.9
3.	2000	4 g	230	1.130	17.7	640	6.2	9.5	15.7
4.	2500	1 g	92	.361	55.4	560	15.8	12.3	28.1
5.	2500	2 g	138	.541	37.0	650	12.8	14.5	27.3
6.	2500	4 g	230	.902	22.2	745	9.0	14.0	23.0

TABLE III

Air pressure, etc., in high altitudes according to Dr. Hohmann's formula:

$$\gamma/\gamma_0 = (1 - h/400,000)^{5.2}$$

altitude km	g, m/sec ²	mm Hg	weight of 1 m ³ air in kg.
0	9.8100	760.0	1.30
1	9.8068	675.0	1.15
2	9.8042	598.0	1.00
3	9.8010	528.0	0.90
4	9.7978	466.0	0.80
5	9.7945	410.0	0.70
6	9.7915	360.0	0.62
8	9.7857	277.0	0.48
10	9.7794	210.0	0.375
15	9.7640	89.66	0.215
20	9.7498	40.99	0.105
30	9.7182	8.63	0.0283
40	9.6880	1.84	0.00740
50	9.6580	0.40	0.00187
60	9.6278	0.094	0.000448
70	9.5982	0.0274	0.0001025
80	9.5682	0.0123	0.0000230
90	9.5388	0.0081	0.0000049
100	9.5094	0.0067	0.98×10^{-4}
200	9.2220	0.0001	0.23×10^{-10}
400	8.6874	0.0000	0.00000

ADDENDA TO CHAPTER 10.

Page 237.

*Note on Usable Fuels **

The following table shows the chemical reactions taking place in the combustion of various liquid fuels and the theoretical exhaust velocities. The equation for pure carbon has been included for comparison.

NAME	REACTION	THEORETICAL
		EXHAUST VELOCITY (meters per second)
<i>Oxygen in the form of oxygen:</i>		
Hydrogen:	1 kg H ₂ + 8 kg O ₂ = 9 kg H ₂ O	5170
Methane:	1 kg CH ₄ + 4 kg O ₂ = 5 kg CO ₂ and H ₂ O	4490
Gasoline:	1 kg C ₈ H ₁₈ + 3.5 kg O ₂ = 4.5 kg CO ₂ and H ₂ O	4450

* The tables in this Note are condensations of more extensive tables published in Dr. Eugen Sänger's book *Raketenflugtechnik*.

Benzene:	1 kg C_6H_6 + 3.4 kg O_2 = 4.4 kg CO_2 and H_2O	4270
Alcohol:	1 kg C_2H_5O + 2.08 kg O_2 = 3.08 kg CO_2 and H_2O	4180
Carbon:	1 kg C + 2.67 kg O_2 = 3.67 kg CO_2	4320

Oxygen in the form of ozone:

Hydrogen:	1 kg H_2 + 8 kg O_3 = 9 kg H_2O	5670
Methane:	1 kg CH_4 + 4 kg O_3 = 5 kg CO_2 and H_2O	5000
Gasoline:	1 kg C_8H_{18} + 3.5 kg O_3 = 4.5 kg CO_2 and H_2O	4960
Benzene:	1 kg C_6H_6 + 3.4 kg O_3 = 4.4 kg CO_2 and H_2O	4800
Alcohol:	1 kg C_2H_5O + 2.08 kg O_3 = 3.08 kg CO_2 and H_2O	4630
Carbon:	1 kg C + 2.67 kg O_3 = 3.67 kg CO_2	4800

The products of the combustion are always either water (in the form of vapor) or carbon dioxide or a mixture of both.

Hydrogen and oxygen with hydrogen surplus:

1 kg H_2 + 8 kg O_2	5170
1 kg H_2 + 8 kg O_2 + 0.5 kg H_2	5030
1 kg H_2 + 8 kg O_2 + 1.0 kg H_2	4890
1 kg H_2 + 8 kg O_2 + 1.5 kg H_2	4770
1 kg H_2 + 8 kg O_2 + 2.0 kg H_2	4680
1 kg H_2 + 8 kg O_2 + 2.5 kg H_2	4570
1 kg H_2 + 8 kg O_2 + 3.0 kg H_2	4470

Explosives:

Nitro-glycerine $C_3H_5(ONO_2)_3$	3880
Nitro-cellulose $C_6H_{10}O_5 + 4 NO_2$	3660
Dynamite	3300
Smokeless Powder	3240
Picric Acid $C_6H_3(NO_2)_3OH$	2600
Black Powder	2420

Most of these substances are not usable for obvious reasons. The *measured* exhaust velocity of ordinary rocket powder (black powder with carbon surplus) averages 600 meters per second.

Note on Penetration Bombs

Page 193.

The table on page 345, showing velocities of bombs released from dive bombers at various altitudes, with and without rocket charges, is from an article "How about Penetration Bombs?" *U. S. Naval Institute Proceedings*, December 1941. It was assumed that: a cordite rocket with an exhaust velocity of 5900 fps was used; the weight of the charge was about 12 lb; burning time of the rocket charge was 2 sec; the thrust, consequently, 495 kg or a little over 1000 lb. Dimensions of the bombs (actual German makes) were:

	BOMB		
	1	2	3
Weight (kg.)	104	250	500
Diameter (mm.)	254	457	620
Length (mm.)	1270	1828	2160
Terminal velocity, fps (computed)	980	920	940

APPENDIX 2

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Drag coefficient was assumed to be approx. 0.25; the stabilizing fins were neglected.

SPEED OF DIVE BOMBER (mph)	ALTITUDE OF BOMB RELEASE, (ft)	ROCKET THRUST, (kg)	DURATION OF ROCKET THRUST, (sec)	DURATION OF BOMB TRAJECTORY, (sec)	IMPACT VELOCITY OF BOMB, (fps)	KINETIC ENERGY OF BOMB, (ft-lb)	RATIO OF KINETIC ENERGIES
--	--	---------------------------	--	--	--	---	------------------------------------

Bomb 1; weight 104 kg (229 lb)

200	1000	0	—	3.0	382	520,000	1.00
		495	2	2.1	656	1,530,000	2.95
	2000	0	—	5.4	450	720,000	1.00
		495	2	3.6	689	1,690,000	2.34
	3000	0	—	7.4	506	910,000	1.00
		495	2	5.0	719	1,840,000	2.01

Bomb 2; weight 250 kg (550 lb)

200	1000	0	—	3.0	379	1,240,000	1.00
		495	2	2.5	489	2,050,000	1.66
	2000	0	—	5.4	445	1,700,000	1.00
		495	2	4.5	536	2,470,000	1.46
	3000	0	—	7.5	498	2,130,000	1.00
		495	2	6.2	575	2,850,000	1.34

Bomb 3; weight 500 kg (1100 lb)

200	1000	0	—	3.0	380	2,480,000	1.00
		495	2	2.7	434	3,230,000	1.30
	2000	0	—	5.4	446	3,420,000	1.00
		495	2	4.8	490	4,130,000	1.21
	3000	0	—	7.5	501	4,310,000	1.00
		495	2	6.8	539	4,980,000	1.16

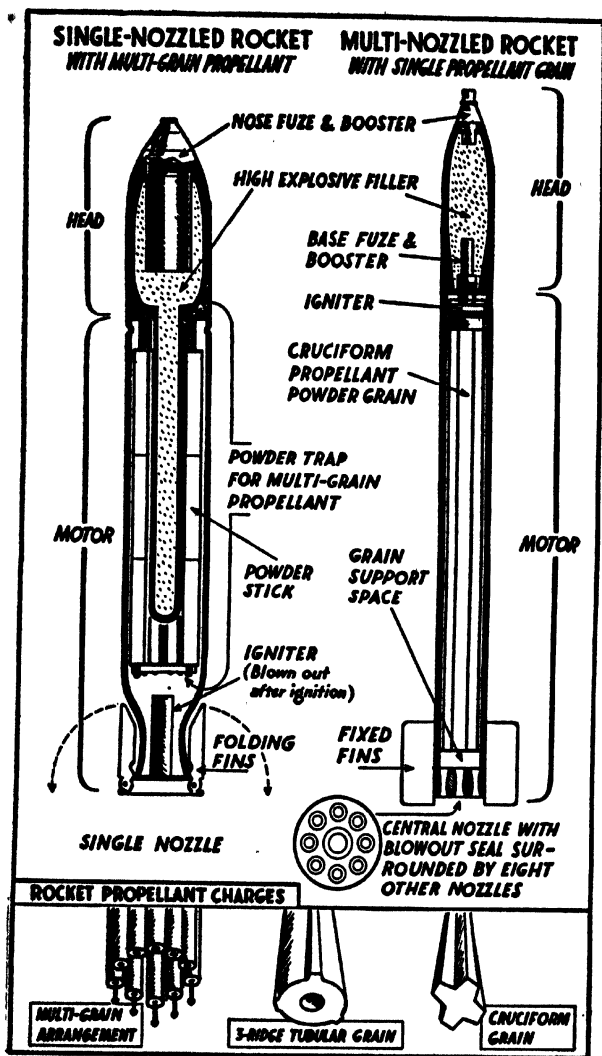
U. S. Rocket Ordnance, Second World War

PORTABLE ROCKET WEAPONS

Bazooka. Anti-tank rocket with shaped charge. Effective range 200 yd, for direct fire. Diameter of propelling rocket, 2.36 in. The same rocket existed with a head filled with white phosphorus for smoke and incendiary action.

Super bazooka. Improved anti-tank rocket with shaped charge. Dimensions same as those of the original model, but with heavier propelling charge, extending the effective range to 700 yd.

Bazooka, 3.5-inch. Details of this rocket still secret.



48. Modern American War Rockets.

This drawing shows the principles of construction of the most important types of American ordnance rockets used in the Second World War. The rocket shown at left is of the type of the 4.5-inch M-8, the one at right is "Holy Moses," the 5-inch HVAR airborne rocket. (Courtesy OSRD.)

AIRBORNE ROCKETS

Retro-rocket. Anti-submarine weapon fired from planes backward with velocity matching plane speed so that the weapon fell vertically. There were three different rocket bodies to match the flying speeds of three airplane types. The head of the rocket was modified from the "mousetrap rocket" (*see below*) and carried 35 lb of high explosive. Retro-rockets sank the last "probable" German submarine in the war, on April 30, 1945.

Retro-float light. Same as above but fitted with flare.

3.5-inch anti-submarine rocket. Rocket with fixed fins. Length 54½ in., total weight 54 lb. Propelled by one 8.5-lb "grain," fitted with 20-lb solid steel heads.

3.5-inch anti-submarine rocket. Same rocket but fitted with 50-lb 5-in. high-explosive warhead.

4.5-inch Aircraft Rocket M-8. Total weight 38 lb; fitted with warhead containing 5 lb of high explosive. At first with fixed fins, replaced later by folding fins. Was fired from three tube clusters carried under the wings.

115-mm Aircraft Rocket. Also called the "super 4.5-in." Length 6 ft, total weight 103 lb, weight of warhead 40 lb, with four fixed fins. Had longer range and was more accurate than M-8. Two types of heads: one with 8.5 lb of high explosive in fragmentation casing, the other a semi-armor-piercing type.

5-inch HVAR (High Velocity Aircraft Rocket) nicknamed "Holy Moses." Over-all length 6 ft, over-all weight 140 lb. This type, introduced in combat in July 1944, became the most used air-to-ground rocket of the U. S. armed forces.

"Tiny Tim." Total length 10 ft 3 in, diameter 1½ in, over-all weight 1284 lb. Warhead weight 590 lb, containing 150 lb of TNT. Weight of propelling charge, consisting of four "grains," 146 lb. Was launched by dropping it from plane with a lanyard attached to both plane and rocket. Rocket was ignited when lanyard was pulled taut. First test in August 1944, only combat use: Okinawa.

"Unfortunately, the results could not be accurately assessed. There were, it seems, so many things being thrown at the Japs on Okinawa that it was impossible to distinguish the wreckage caused by 'Tiny Tim' from the general destruction." (*From the official release on U. S. ordnance rockets.*)

GROUND-TO-GROUND AND BARRAGE ROCKETS

4.5-inch M-8. Same as listed above. Had 4000-yd range when used as a ground-to-ground weapon, was used with fixed fins by Navy as a barrage rocket and with folding fins by Army. Multiple launchers developed for this weapon were Xylophone (8 tubes) and Calliope (60 tubes).

4.5-inch smoke rocket. Adaptation of the same rocket for laying of smoke screens. Range 1100 yd. Smoke-producing agent was at first "FS liquid smoke" (a mixture of sulphurtrioxide and chlorosulphonic acid), later white phosphorus. The 3.5-in. aircraft rocket was also adapted as a smoke rocket.

7.2-inch demolition rocket. Warhead carried 32 lb of high explosive. The

launcher devised for this rocket was nicknamed Whiz Bang, while the Navy 120-round launcher for the same rocket was called Woofus.

7.2-inch chemical rocket. Range up to 3000 yd. Was used for smoke composition and could have been used for poison gas. Each rocket carried 20 lb of chemicals. The chemical 7.2-in rocket had a special 24-round launcher, nicknamed Grand Slam.

4.5-inch spinner M-16. Spin-stabilized rocket of same over-all weight as M-8, but with a range of 5250 yd and slightly heavier warhead. Launchers for this weapon: Honeycomb (24 tubes) and Hornet's Nest (60 tubes). A proximity fuze for these rockets was developed but was not used in action.

3.5-inch spinner rocket. Experimental only, not introduced.

5-inch spinner rocket. Range 700-1000 yd, for penetrating flat angle fire. Over-all weight 50 lb, over-all length 30 in. Like the 115-mm Aircraft Rocket it came with semi-armor-piercing head and with general-purpose head.

5-inch spinner barrage rocket. Over-all weight 50 lb, over-all length 32 in, range 5000 yd. Two other spinner barrage rockets of the same caliber, but with ranges of 2500 and 1250 yd, respectively, were under development, but only the 5000-yd-range type saw action.

SPECIAL APPLICATIONS

"Minnie Mouse." The rocket fired from the "mousetrap" submarine killers. The warheads were fitted with impact fuzes which would work only under water. A weapon of the same purpose as the old depth charge thrower.

"Window rocket." 3.5-in aircraft rocket adapted for the carrying of "radar window," length of aluminum foil which causes spurious readings in enemy radars. Each rocket carried over 75,000 pieces of foil, $\frac{3}{16}$ in wide and from $1\frac{1}{2}$ to 16 in long.

AA target rocket. A 3.5-in rocket with large plywood fins, a range of 1 mile, and a speed of 360 mph, used for training in anti-aircraft gunnery.

Harpoon rocket. A line-carrying rocket with a pointed head with four folding spades and two 4.5-in rockets in tandem. The first rocket did the actual carrying; the second, ignited by delay fuze, forced the pointed head deep into the ground. Pull on the line expanded the spades.

"Snake." A ski-like structure 100 ft long, assembled from metal plates 5 ft long and 5 in wide, with TNT clamped to plates; the whole propelled by a 4.5-in rocket mounted at the head of the device. Used to detonate a path through enemy mine fields.

ADDENDUM TO CHAPTER 9.

Details of V-2

During a lecture delivered in London before the Royal Aeronautical Society on November 1, 1945, the lecturer, W. C. A. Perring, F. R. Ae.S., made the following details of V-2 public:

Dimensions (general)

Over-all length of rocket A-4 (V-2)	46 ft
Length of conical warhead	5 ft 11 in.
Length of instrument section	4 ft 8 in.
Length of fuel tanks	20 ft 3½ in.
Length of power bay (rocket motor, etc.)	14 ft 7½ in.
Maximum diameter of rocket	5 ft 5.3 in.
Diameter over fins	11 ft 8 in.

Weights (general)

Take-off weight, fully fueled	12.5 tons
Weight empty, with warhead (8,900 lb . . .)	about 4 tons
Warhead (filled with <i>amatol</i>)	2,150 lb
Full load liquid oxygen	10,940 lb
Full load alcohol (some used for cooling)	8,370 lb
Total fuel load	19,310 lb
Mass-ratio, approx. 3:1	
Mass-ratio without warhead, approx. 4:1.	

*Weights (in pounds) of detail**Instrument compartment*

Radio compartment and frames	325
Radio equipment and mountings	155
Instruments, wiring, etc.	415
Compressed nitrogen, fittings, etc.	80
	<hr/> 975

Fuel Tanks

Structure and glass wool insulation	1185
Oxygen tank and fittings	375
Alcohol tank and fittings	235
	<hr/> 1795

Control surfaces

Fins (stabilizers)	750
Internal vanes, etc.	470
External control, etc.	115
	<hr/> 1335

Propulsion unit

Steel structure, mountings, etc.	670
Turbine-pump unit	880
Rocket motor and fittings	1025
<i>T-Stoff</i> for turbine	370
Permanganate for turbine	29
	<hr/> 3044

*Dimensions and performance of propulsion unit**Turbine*

Diameter of blades	18½ in.
Working pressure	330 lb/in.²

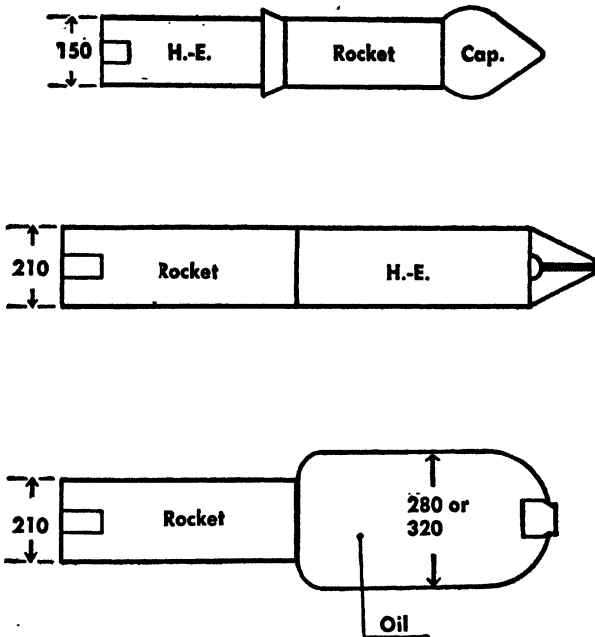
Dimensions and performance of propulsion unit (continued)

Power (estimated)	680	HP at 5000 rpm
Endurance	about 113	sec
Oxygen pump		
Impeller diameter	10.55 in.	
Flow at 5000 rpm	160	lb/sec
HP at 5000 rpm	320	
Delivery pressure	350	lb/in. ²
Alcohol pump		
Impeller diameter	13.45 in.	
Flow at 5000 rpm	125	lb/sec
HP at 5000 rpm	380	
Delivery pressure	370	lb/in. ²
Rocket motor		
Over-all length: approx.	5	ft 8 in.
Diameter of combustion chamber	3	ft 1 in.
Throat diameter	1	ft 4 in.
Nozzle diameter	2	ft 5 in.
Fuel consumption	275	lb/sec
Exhaust velocity *	7000	fps
Pressure in chamber *	294	lb/in. ²
Pressure in throat *	157	lb/in. ²
Pressure at nozzle *	14.7	lb/in. ²
Endurance at full flow *	70	sec
Thrust (at sea level)	60,000	lb (27 tons)
Thrust (at about 25 miles)	69,000	lb
Performance of rocket		
Operational range	180-190	miles
Maximum observed range	220	miles
Operational peak altitude	60	miles
Maximum velocity	5000	fps
Acceleration at take-off	about 1.2g	eff.
Maximum acceleration	about 6.5g	eff.

Angle formed by longitudinal axis of rocket with reference to the horizontal:

SECONDS AFTER TAKE-OFF	ANGLE
0	90°
2.0	90°
8.5	80°
11.5	76°
28.5	60°
47.0	46°
52.0	44°

Maximum temperature of outer skin (determined by the Germans by inserting a number of plugs of various metals of known melting points) 647 deg Centigrade.



49. Projectiles of German Rocket Launchers.

TOP: The projectile of the Nebelwerfer.

CENTER: The later, larger version of the Nebelwerfer.

BOTTOM: The Schweres Wurfgerät high-explosive and incendiary rockets.

Note on the Mass-Ratio of Step Rockets

If we call the mass-ratios of three rockets which form one three-step rocket: M'_0/M'_1 , M'_1/M'_2 , and M'_2/M'_3 , the "ideal mass-ratio" of that three-step rocket becomes:

$$m_0/m_1 = \frac{M'_0 + M'_1 + M'_2}{M'_1 + M'_2 + M'_3} \times \frac{M'_1 + M'_2}{M'_2 + M'_3} \times \frac{M'_2}{M'_3}$$

which shows that the "ideal mass-ratio" is the *product* of the individual mass-ratios. The velocities v' , v'' , and v''' are added so that the final velocity of the third step $v_f = v' + v'' + v'''$.

For the following example it is assumed that each one of the three rockets has a mass-ratio of 4:1 and that the M_1 of each step is equal in mass to the M_0 of the higher steps. The masses of the example are:

* Approximations and estimates.

ROCKETS

	M_0	M_1
First step:	224 tons	32 tons
Second step:	28 tons	4 tons
Third step:	4 tons	1 ton

Giving the following result:

$$\begin{aligned}
 m_0/m_1 &= \frac{224 + 28 + 4}{32 + 28 + 4} \times \frac{28 + 4}{4 + 4} \times \frac{4}{1} \\
 &= \frac{256}{64} \times \frac{32}{8} \times 4 = 64
 \end{aligned}$$

Hence the "ideal mass-ratio" of this three step rocket is 64:1; the take-off weight of the whole is $224 + 28 + 4 = 256$ tons. Each step would produce a velocity of $1.4c$ so that v_f would be $1.4 + 1.4 + 1.4 = 4.2c$. Assuming a uniform exhaust velocity c of 2100 mps (the c of V-2), the third step would have a final velocity of 8820 mps which is slightly higher than the velocity required to reach the station in space.

ADDENDUM TO CHAPTER 10

The "Problem of Synergy"

Oberth defined the term "problem of synergy" which he coined for the purpose as the problem of transferring as much as possible of the available energy to the rocket and as little as possible to the gases of the exhaust. The problem of synergy, consequently, refers to the most advantageous movement of the rocket; it comprises everything which is not a problem of motor or of rocket design. One might say that the synergic problem compares to the tactical use of a weapon after it has been designed, developed, and tested.

Oberth expressed it in the formula $\frac{dA}{dm} = c \times \cos a \times v$

which gives the ratio between the increase of energy (of the rocket) dA and the mass expenditure dm . As usual c is the exhaust velocity and v the rocket velocity while a is the angle between the direction of rocket movement and direction of the thrust P .

Reasoning from this formula, Oberth developed the following three points:

- (1) c must be as high as possible—but the formula shows that the maximum value of c is only part of what has to be done for optimum fuel economy.
- (2) since $\cos a$ becomes largest when $a = 0$, the direction of P and of the rocket movement should coincide if at all possible.
- (3) the factor v indicates that the faster the rocket is moving when the additional burning takes place, the more will dA increase.

Hence the following demands should be made:

- A. The rocket should ascend with high acceleration (this, of course, is valid only *after* air resistance has been eliminated by altitude).

B. The rocket should not ascend vertically. Theoretically a horizontal "ascent" would be best (but is impossible because of air resistance).

C. The horizontal component of the ascent curve should point East in order to utilize the earth's rotation.

D. "*Zusammenlegung der Stösse*" (condensation of power application) is needed to comply with point (3) because it will result in generally higher rocket velocities while burning than would occur if the applications of power were separated by considerable intervals of time.

The compromise between this set of demands and the existence of air resistance is the synergic curve pictured and discussed in the body of the book.

Although the moon would be far inferior to the Outer Station as a base for space travel, Dr. Hohmann calculated a number of trips from the moon, in consideration of the possibility that water might be found there so that the manufacture of fuels would be possible. The following table shows the results, under the usual assumptions:

INITIAL MASS IN TONS, WITH 6 TONS AS FINAL WEIGHT

TRIP:	DURATION (in days)	EXHAUST VELOCITY AVAILABLE (meters per second)			
		3000	4000	5000	10,000
Earth to Moon	4	1420	360	153	31
Moon to earth	3	15	12	10	8
Moon to Venus	146	123	68	46.5	24
Moon to Mars	258	780	278	142	44
Venus to earth	146	2510	690	276	64
Mars to earth	258	382	182	110	41
Moon, circling of Venus, earth	762	1060	423	244	92
Moon, circling of Mars, earth	971	1720	630	352	116
Round trip:					
Moon→orbit of Mars→orbit of Venus→earth.	546	1220	446	245	80

Landing on the planet with a small rocket for one passenger with a final weight of 1 ton, while ship is circling planet; small rocket is left behind after return of its pilot to the ship (final weight 6 tons, as usual):

Moon-Venus- earth	762	1870	601	299	101
Moon-Mars- earth	971	2432	790	410	125

TABLE OF ESCAPE VELOCITIES, ETC.

PLANET	MASS earth = 1	G AT SURFACE earth = 1	ESCAPE VELOCITY		ORBITAL VELOCITY	
			miles per second	kilo- meters per second	miles per second	kilo- meters per second
Mercury	0.04	0.27	2.2	4.3	29.7	47.7
Venus	0.81	0.85	6.3	10.3	21.7	35.1
Earth	1.00	1.00	7.0	11.2	18.5	29.7
Mars	0.11	0.38	3.1	5.04	15.0	24.1
Jupiter	317.0	2.64	37.0	59.5	8.1	13.0
Saturn	95.0	1.17	22.0	35.4	6.0	9.6
Uranus	14.7	0.92	13.0	21.6	4.2	6.8
Neptune	17.2	1.12	14.0	22.8	3.4	5.4
Moon	0.012	0.16	1.47	2.37	0.64	1.03

ADDENDUM TO CHAPTER 12

An interesting problem of meteorite distribution in space is posed by the zodiacal light. It is certain that the zodiacal light is caused by the reflection of sunlight from meteoric matter arranged in the shape of a lens with the sun in its center and extending some distance beyond the orbit of earth. The reflected light shows very little polarization and it cannot, therefore, be reflected by very fine dust or by gas molecules. To account for the observed brightness of the zodiacal light one would have to assume one meteorite 1 mm in diameter every 5 miles. Or, if it is assumed that the meteorites are fairly large, one meteorite 10 ft in diameter every 1000 miles—*provided that they are of a rather dark grayish color*. If they are lighter in color their numbers would decrease considerably and therefore the distance between them increase.

The albedo (relative brightness) of these meteorites is, of course, a matter of speculation to a large extent, but Robertson proved in 1939 that they must be relatively large and far apart. He has shown that a body revolving around the sun, receiving heat from it and radiating it into space again, must gradually approach the sun in a tightening spiral, finally to be consumed by the sun. The time required for this gradual approach is long, it amounts to

$$7 \frac{aDR^2}{\text{million years}}$$

where a is the radius of the body in centimeters, D its density in grams per cubic centimeter, and R its initial distance from the sun in astronomical units (one astronomical unit is the distance of the earth from the sun). Therefore a body will resist the longer, the larger it is, the denser it is, and the farther away it is from the sun. For a body the size and weight of earth the result is

virtually infinity, but for a ball of ordinary rock, 10 mm in diameter and starting out near earth, the time would be 20 million years. Since the age of meteorites is on the order of 2000 million years the meteorites causing the zodiacal light have to be large and far apart.

The White Sands Proving Ground

On the 20th of February 1945, the Secretary of War approved the establishment of a large-scale proving ground for long-distance rockets and guided missiles at a site previously selected by a representative of the Office of the Chief of Ordnance and representatives of the Engineer Corps. The site chosen was an area of desert land, extending due north into the state of New Mexico from the Texas-New Mexico state line north of El Paso, Tex. Because this area embodies the site of the White Sands National Monument, established earlier by a subdivision of the Department of the Interior, the rocket testing area was named the White Sands Proving Ground.

The White Sands Proving Ground is of a generally rectangular shape, narrowing toward the southern baseline. It extends 125 miles in a north-south direction, and is 41 miles wide at the northern end. The launching area and the permanent facilities, such as test stands, launching towers, concrete observation buildings, and quarters for the personnel, are located in the southern section of the proving ground, near the Organ Mountains and not far from Highway Route 70, which crosses the southern part of the proving ground diagonally. To the west this highway leads to Las Cruces, N.M.; to the east to Alamogordo, which is just beyond the borderline of the proving ground.

Route 80 leads from Las Cruces to El Paso, Texas, skirting the southwestern corner of the proving ground. The so-called "Impact Area" is located in the northern part of the proving ground, which is flanked for almost its entire length by the San Andres Mountains in the west and the Sacramento Mountains in the east.

The valley which forms the proving ground lies at an elevation of 4000 ft. above sea level, while the two flanking mountain ranges run up to 10,000 ft. The major portion of the valley is typical southwestern desert, with some special features such as formations of black lava in the northern section, produced originally by a now long-extinct volcano. The east-central section of the proving ground is characterized by enormous shifting dunes of white gypsum sand, which caused the naming of the National Monument and subsequently of the proving ground.

The area was selected not only because several military establishments, including the Alamogordo Air Base and Fort Bliss, are near by, but also because there is only one highway, because most of the land is under either federal or state control, and mainly because the area is very thinly settled. There is only one industrial enterprise (a small talc-mining firm) in the San Andres Mountains, and a few scattered ranchers' homes on the poor grazing land at and near the borders of the proving ground.

The first work done on the White Sands Proving Ground was connected with the testing of a number of captured German V-2 rockets, with the aid of captured German technicians. At the end of July 1945, the transportation of

about 300 carloads of V-2 components began; the total number of V-2 rockets which could be assembled from these parts was 25.

However, the first rocket to rise from the White Sands Proving Ground was not a captured V-2, but an American high-altitude rocket which became known as WAC Corporal. The rocket itself was constructed by Douglas Aircraft Company, and the rocket motor was designed and built by Aero-Jet.

The rocket was built of steel and aluminum, with magnesium in some places, had a long nose which was literally needle-pointed, and three tail fins. The over-all length of the WAC Corporal was 16 ft., the diameter 1 ft. The WAC Corporal was fired with the aid of a booster rocket from a high launching tower located near the control block house, which, incidentally, has concrete walls 10 ft. thick and a pyramidal roof of reinforced concrete 27 ft. thick at the apex. It reached an altitude of 230,000 ft.

The first ground tests with V-2 motors began in March 1946; the first ascent of a V-2 from the White Sands Proving Ground took place in April 1946. On May 10, 1946, the first V-2 ascent before invited spectators and representatives of the press was made. After that test one V-2 firing took place every week, with irregular gaps in the succession. One of the V-2's exploded during take-off, close to the ground, and another one exploded at an altitude of about 5000 feet.

The record shot of a V-2 took place on July 30, 1946, carrying to an altitude of 104 miles, which exceeds by more than 50 miles the altitude reached by any other type of rocket and by about 20 miles all previous vertical ascents of V-2 rockets.

BIBLIOGRAPHY

Section I

WORKS ON ROCKETS, APPLICATION AND THEORY

NOTE TO THE SECTION ON ROCKET LITERATURE:

The following bibliography is, to the best of my knowledge, complete as far as publications in book or pamphlet form are concerned. It does not contain articles published in periodicals since most of these articles are by now either obsolete or have been duplicated in books. Some articles that were for some reason significant, as well as some patents, have been mentioned in the text of the book; they have not been listed again in the bibliography.

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Jähns, O. *Geschichte der Explosivstoffe*. Vol. I. Berlin, 1897. This gives the history of war rockets in general.

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Moore, W. *On the Motion of Rockets*. London, 1810.

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Pictet, Adolph. *Essai sur les propriétés et la tactique des Fusées de Guerre*. Turin, 1848.

Rogier, Charles. *A Word for My King and Country: A treatise on the utility of a rocket armament, assisted by balloons where ships of war cannot be accessible; both defensive and offensive, to the annoying of the enemy's harbour*. Macclesfield, 1818.

Romocki, S. J. von. *Geschichte der Explosivstoffe*. 2 vols. Berlin, 1898. Still the best book on the history of gunpowder, explosives, firearms, and military rockets.

Scoffern, J. *Projectile Weapons of War*. 1859.

This is one of the large numbers of books on weapons and military matters published during the nineteenth century which contain a description of war rockets. Similar articles can be found in many others, for example, in J. Frost's *Book of the Army of the United States* (1845), in E. S. Farrow's *Military Encyclopedia* (1885) and in the *British Treatise on Ammunition* (His Majesty's Stationery Office), in several editions. The articles on war rockets are not the same in the various editions; generally speaking they are shorter the more recent the edition. The last one is in the edition of 1905. The articles on war rockets in these books and manuals deal with types contemporary or recent at the time these books were printed; they pay no attention to the earlier history.

U. S. Rocket Ordnance; Development and Use in World War II.

Release (on March 31, 1946) by the Office of Scientific Research and Development (OSRD), War Department and Navy Department. An authoritative account of the development, characteristics and tactical employment of American rocket ordnance. 57 pages.

FIREWORKS AND SIGNAL ROCKETS:

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Busch and Hoffmann. *Die Kriegsfeuerwerkerei der Königlich Preussischen Artillery*. Berlin, 1851.

Jones, Robert. *Artificial Fireworks*. London, 1776.

Nye, Nathanael. *A Treatise of Artificiall Fire-Works for Warre and Recreation etc.* . . . London, 1647.

Simienowicz, Kasimir. *Vollkommene Geschütz-/Feuerwerk und Büchsenmeysterey Kunst*. Frankfort (Main), 1676.

Simienowicz was commander of the Polish Army; his book was written in Latin and published in that language, but the Latin text is only a part of the whole plan. The German edition, listed here, is a larger work, finished according to Simienowicz' original plan by Daniel Elrich, Ordnance Master of the city of Frankfort-on-the-Main. The Latin section was translated into German by Leonhard Beer.

Weingart, C. W. *Pyrotechnics, Civil and Military*. Brooklyn, N. Y., 1943. 220 p. The most recent book in English on this subject. Contains a list of pyrotechnical books, beginning with Biringuccio's *Pirotechnia* of 1540 (which contains very little about the subject). Unfortunately that list lacks much desirable information; instead it contains a number of typographical errors. Some of the historical references are not quite accurate.

MISCELLANEOUS

Chaplygin, S. A. *On Gas Jets*. Providence, R. I. (Brown Univ.), 1944. (mimeographed) 113 p. Translation by Maurice H. Slud of Publication No. 21 1904, of the Scientific Annals of the Imp. Univ. of Moscow, Phys.-Math Division.

Crassus, Ing. *Der gefahrlose Menschenflug*. Hamburg, 1912. 37 p.

The author's real name is Wilhelm Gaedicke; the book deals with the project of a helicopter with jet-driven rotor. Only of historical interest.

Footman, David. *Red Prelude*. New Haven, Conn., 1945. 267 p.

This book has nothing to do with rockets directly, but contains the complete story of the trial of Kibaltchitch and his accomplices, mainly Shchelyabov.

Luigi Gussalli. *I Viaggi Interplanetari Per Mezzo Delle Radiazioni Solari*, Brescia (Italy) 1946. 92 pages.

With subtitle: "The Interplanetary Travels by the Solar Radiations, Translated from the original text by Jeanne Wiest." The book advances the idea of abolishing the enormous mass-ratios required for interplanetary journeys by utilization of the energy of solar radiation. The first 60 pages are in Italian, the remaining 32 pages are devoted to a translation (presumed to be English, as testified by the subtitle) of the Italian text.

— *Si può già tentare un viaggio dalla terra alla luna*. Milan, 1923.

The book is devoted to several inventions and ideas of the author. The section on rocket propulsion forms only one chapter.

Jacobs, H. *Schwanzlose Segelflugmodelle*. Ravensburg, 1937. 60 p.

Advice on the design and construction of glider models, among them some powered by powder rockets; also photographs of the latter.

Lorin, René. *L'Air et la vitesse*. Paris, 1919. 94 p.

Contains several chapters on rocket torpedoes, rocket power for airplanes, etc.

Papp, Desiderius. *Was lebt auf den Sternen?* Vienna, 1931. 345 p.

While the title sounds as if the book dealt only with the possibility of life on other planets, a great deal of it is devoted to the problems of interplanetary travel, conjectures about the inhabitants of the planet Mars, etc. It contains a great deal of material but has to be read with many reservations.

Pseudoman, Akkas. *Zero to Eighty*. Princeton, 1937. 283 p.

The book has the subtitle: "Being my lifetime doings, reflections and inventions, also my journey around the moon." Akkas Pseudoman is the pseudonym of Dr. E. F. Northrup, inventor of the Ajax-Northrup high-frequency induction furnace, who died May 1, 1940. For an obituary see the *New York Times* of May 2, 1940. The book, a semi-fictional autobiography, contains a great deal about the author's experiments with solenoid guns, including photographs, and a résumé of the theory of space travel which Dr. Northrup wanted to accomplish by means of rockets initially accelerated in large solenoid guns.

Astronautics, Bulletin of the American Rocket Society, originally called *Bulletin of the American Interplanetary Society*. Started in 1931, at first monthly, then irregularly; now quarterly, printed, mimeographed, and offset.

The Journal of the British Interplanetary Society, since 1933, at first quarterly, then more or less irregular. Publication was stopped with the outbreak of World War II.

PUBLICATIONS OF THE N.A.C.A. (NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS):

Buckingham, Edgar. *Jet Propulsion for Airplanes*. N.A.C.A. Report No. 159.
Campini, Secondo. *Analytical Theory of the Campini Propulsion System*.
Translated from *L'Aerotecnica*, XVIII (January 1938), No. 1. N.A.C.A.
Techn. Mem. No. 1010.

Eastman, Jacobs, and Shoemaker. *Tests on Thrust Augmentors for Jet Propulsion*. N.A.C.A. Techn. Notes No. 431.

Kisenko, M. S. *Comparative Results of Tests on Several Different Types of Nozzles*. (Central Aero-Hydrodynamical Inst. Moscow) N.A.C.A. Techn. Mem. No. 1066.

Roy, Maurice. *Propulsion by Reaction*. Translated from *La Technique Aéronautique*. N.A.C.A. Techn. Mem. No. 571.

Schubauer, G. B. *Jet Propulsion with Special References to Thrust Augmentors*. N.A.C.A. Techn. Notes No. 442.

(See also under German books, Dr. Eugen Sänger.)

Section II

LITERARY HISTORY OF IMAGINATIVE LITERATURE

A complete literary history of that variety of imaginative literature which is based on facts and theories of a scientific nature—so-called "science-fic-

tion"—still remains to be written. The existing books deal mostly with Jules Verne, the first outstanding representative of that field, while some essays are devoted to specific phases.

BOOKS ON JULES VERNE:

Allott, Kenneth. *Jules Verne*. New York, 1941. 282 p.

The first biography of Jules Verne in English, with a good bibliography of his numerous works, fiction, factual, and stage writings.

Claretin, Jules. *Jules Verne. Célébrités Contemporaines*, No. 33. 1883. 32 p.
de la Fuye, Marguerite Allotte. *Jules Verne—Sa vie, son œuvre*. Kra, 1928. 292 p.

Biography of Jules Verne by his niece.

Lemire, Charles. *Jules Verne 1828-1905*. Paris, 1908. 185 p.

Marcucci, Edmondo. *Giulio Verne et la sua Opera*. 1930. 129 p.

Contains a good bibliography of Jules Verne's works and a section on his Italian imitators.

Popp, Max. *Julius Verne und sein Werk*. Hartleben, 1909. 213 p.

Devotes a good deal of space to Verne's imitators, mainly those writing in or translated into German.

Waltz, George H. *Jules Verne, the Biography of an Imagination*. New York, 1943. 223 p.

Shorter than Allott's book, contains interesting notes about the influence of Jules Verne's books.

BOOKS:

Flammarion, Camille. *Les mondes imaginaires et les mondes réels*. Paris, 1865.

The book consists of two sections: the first dealing with the conditions on the surfaces of the planets of our solar system as they were then assumed to be; the second, almost three times as voluminous as the first, consists of a survey of everything ever written about other planets (except strictly astronomical works of then recent date), philosophical as well as theological, including novelistic attempts, like Godwin's *Man in the Moon*. I own a copy of the 1892 edition of this book (21st ed. 12mo. 598 p.) which contains an added section about books published during the interval from 1865 to 1892. Flammarion, in a preface, stated that he then considered the first part of the book obsolete, but did not change it because he had meanwhile rewritten that part in a greatly enlarged form as *Les terres du ciel* (8vo. 600 p.) published for the first time in 1876.

Gove, Philip B. *The Imaginary Voyage in Prose Fiction*. New York (Columbia), 1941. 445 p. Called by its author "a history of its criticism and a guide for its study, with an annotated check list of 215 imaginary voyages from 1700 to 1800." It is an example of the habit of professors of literature of writing exceptionally dull books about exceptionally fascinating themes. The studied dullness of treatment renders it fairly useless, except for the check list which may provide a useful guide to other writers with different qualifications.

ESSAYS:

Debus, Karl. "Raumschiffahrtsdichtung und Bewohnbarkeitsphantasien seit der Renaissance," *Hochland* (Munich, 1926-27); No. 10. Reprinted in a revised and enlarged form as Chapter III of my *Möglichkeit der Welt-raumfahrt*.

Günther, Ludwig. *Kepler's Traum vom Mond*. Leipzig, 1898. Translated from the Latin and with an introduction by Dr. L. Günther. The introduction contains a survey of similar literature in concise and condensed form.

- The original Latin work was first printed at Frankfort in 1634 as *Joh. Keppleri Mathematici olim imperatorii SOMNIUM seu Opus posthumum de astronomia lunari*. It was republished at Frankfort in 1870 as Vol. VIII of *Joannis Kepleri Astronomia Opera Omnia*. Dr. Günther's German translation is the only translation of this work. Kepler's many "notes" are appended.
- Kretzmann, Edwin M. J. "German Technological Utopias of the Pre-War Period, *Annals of Science*, III (October 1938), No. 4. A great portion of the essay is devoted to Kurd Lasswitz.
- Laffeur, Laurence J. "Marvelous Voyages," *Popular Astronomy*, L— (January 1942), No. 1—.
- McColley, Grant. *Introduction* to Bishop Francis Godwin's *The Man in the Moone* and *Nuncius Inanimatus*. *Smith College Studies in Modern Languages*, XIX (October 1937), No. 1. The reprint of *The Man in the Moone* is from the first edition (London, 1629) and that of the *Nuncius Inanimatus* is from the first edition published in London in 1638. The first editions were both represented by unique copies before the reprint was made. The *Nuncius Inanimatus* is accompanied (on opposite pages) by the English translation of Dr. Thomas Smith of Magdalen College, Oxford, which accompanied the Latin text in the second edition (London, 1657).
- Nicolson, Marjorie Hope. *A World in the Moon*. *Smith College Studies in Modern Languages*, XVIII (1936), No. 2. An essay on the influences of astronomical discoveries on English literature during the seventeenth and eighteenth centuries.
- . *Cosmic Voyages*. *ELH, A Journal of English Literary History*, VII (June 1940), No. 2.
- Nicolson, Marjorie, and Mohler, Nora M. "Swift's 'Flying Island' in the Voyage to Laputa," *Annals of Science*, II (October 1937), No. 4.
- . *The First "Electrical" Flying Machine*. *Smith College Studies in Modern Languages* (October 1939).
- Navis Aeria* of B. Zamagna. Rome 1786. Translated from the Latin by Mary B. McElwain. With introduction by Marjorie Hope Nicolson. *Smith College Classical Studies*, No. 12. Northampton, Mass., March 1939.

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